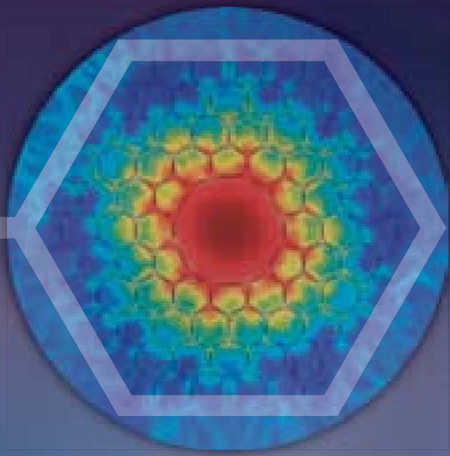
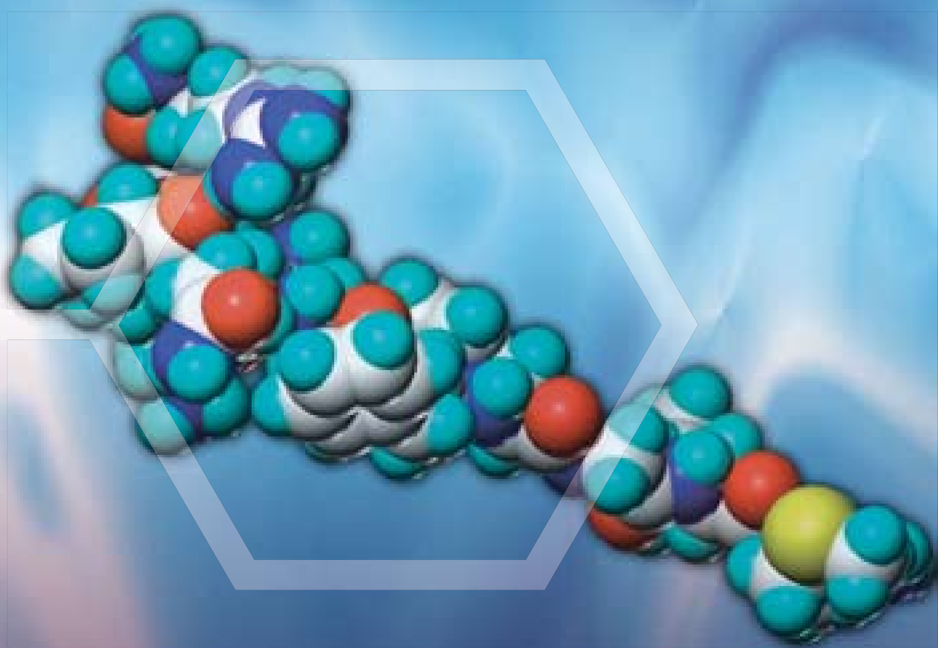


DEFENCE TECHNOLOGY STRATEGY

for the demands of the 21st century



MINISTRY OF DEFENCE

science | innovation | technology

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Defence Values for Acquisition

This statement of values is intended to shape the behaviour of all those involved in acquisition, including Ministers, Defence Management Board members, customers at all levels, the scrutiny community, project teams in the various delivery organisations and our private sector partners.

Everything we do is driven by the Defence Vision:

> ## The Defence Vision
>
> Defending the United Kingdom and its interests
>
> Strengthening international peace and stability
>
> **A FORCE FOR GOOD IN THE WORLD**
>
> We achieve this aim by working together on our core task to produce battle-winning people and equipment that are:
>
> - Fit for the challenge of today
> - Ready for the tasks of tomorrow
> - Capable of building for the future

By working together across all the Lines of Development, we will deliver the right equipment and services fit for the purpose required by the customer, at the right time and the right cost. In delivering this Vision in Acquisition, we all must:

- **recognise that** people are the key to our success; **equip them with the right skills, experience and professional qualifications;**
- **recognise the** best can be the enemy of the very good; **distinguish between must have, desirable, and nice to have if affordable;**
- **identify** trade offs between performance, time and cost; **cases for additional resources must offer realistic alternative solutions;**
- never assume additional resources **will be available; cost growth on one project can only mean less for others and for the front line;**
- **understand that** time matters; **slippage costs – through running on legacy equipment, extended project timescales, and damage to our reputation;**
- **think** incrementally; **seek out agile solutions with open architecture which permit "plug and play"; allow space for innovation and the application of best practice;**
- quantify risk **and reduce it by placing it where it can be managed most effectively; stopping a project before Main Gate can be a sign of maturity;**
- recognise and respect the contribution made by industry; **seek to share objectives, risks and rewards while recognising that different drivers apply;**
- **value** openness and transparency; **share future plans and priorities wherever possible to encourage focused investment and avoid wasted effort;**
- **embed a** through life culture **in all planning and decision making;**
- **value** objectivity **based on clear evidence rather than advocacy; ensure that we capture past experience and allow it to shape our future behaviour;**
- **realise that** success and failure matter; **we will hold people to account for their performance.**

Ministers and members of the Defence Management Board will play their part in working together for Defence by:

- speeding decision taking
- keeping the approval process simple
- empowering teams to deliver

MINISTRY OF DEFENCE

DEFENCE TECHNOLOGY STRATEGY

for the demands of the 21st century

science | innovation | technology

Foreword

Defence Technology Strategy

Foreword by Lord Drayson, Minister Defence Procurement

In order to meet the challenges of the future we must derive the full benefits of advancing technology[1]

The UK continues to face challenging and uncertain threats to its security. Our Armed Forces must be prepared to conduct a wide range of operations from conflict prevention through counter-terrorist operations to high-intensity warfighting. To do this, it is critical that government and industrial Research and Development (R&D) investment in science and technology is properly targeted to ensure we provide effective and affordable military capability that can be maintained and developed throughout its life. This Defence Technology Strategy (DTS) provides the clarity and direction needed for success by describing the underpinning technologies that are important to Defence. For the first time we are publishing an unclassified, openly available document setting out the MOD's priorities for the science and research community[2].

The Defence Industrial Strategy, published last year, clearly set out the industrial capabilities needed in the UK to ensure we can continue to operate our equipment in the way we choose. It highlighted that science and technology is a vital enabler of our national defence capability, and challenged the defence science and technology community[2], government, industry and academia, to:

- develop an improved approach to technology insertion
- work to identify national sources of innovation
- improve the pull-through of technology
- exploit synthetic environments and experimentation
- improve the science and technology skills base within Defence
- increase investment in systems engineering skills and training
- review the Defence research programme
- work to better understand the underpinning technologies that the UK must have for security and sovereignty reasons.

This DTS document meets that challenge.

Throughout our history, innovation in technology has been a key driver of change, national productivity and wealth creation. The defence and security arenas are no exception, and never more so than at the beginning of the 21st century, where it continues to play a key role in the effectiveness and agility of UK military forces. Night vision goggles, precision weapons, stealth techniques and advanced vehicle armour are but a few examples of how science and technology has benefited defence. In current operations, the technology employed in improved body armour, medical treatments and in countering improvised explosive devices will continue to transform how we deliver our capability in an evolutionary manner ever closer linked with technology advances in the civil sector. Recent analysis[3] has demonstrated a strong correlation between national defence R&D investment and equipment quality and export performance.

The UK has a very strong and vibrant science base from which to draw. We remain second only to the US in scientific excellence as measured by citations[4]. With just 1% of the population, the UK undertakes 5% of the world's research, publishes over 12% of all cited papers and almost 13% of papers with the highest impact[5]. UK scientists claim about 10% of the major science international prizes every year. Our higher education institutions are ranked well internationally with six UK institutions in the EU top ten and four London institutions in the world top 50.

However, we cannot afford to be complacent. Significant challenges face us if the UK is to maintain its global position as a major innovator in technologies for both the civil and defence sectors.

The Government has set a target to raise national investment in R&D to 2.5% of GDP by 2014[6] . The Government has increased its own national R&D spending and is looking to industry to play its part in investing to meet this target. The defence sector must retain world class capability in areas critical to operational sovereignty and national security. We must remain an attractive partner for collaboration and an intelligent customer for systems and technologies procured from the global supply base.

This DTS provides direction on where we should focus our research and how we must push promising research into a development pipeline and on to exploitation. It identifies those areas that are key to our national interests; where we could meet our defence needs through collaboration; and where we might rely on off-the-shelf purchase from the global supply base. It is a major step forward in the actions we must take to maintain R&D investment at an appropriate

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[1] *Defence White Paper 2003*
[2] *DIS, Section C1.35 and ff.*

[3] *Middleton, Burns et al, "The Effect of Defence R&D on Military Equipment Quality" published in Defence and Peace Economics, April 2006*
[4] *Science and Innovation framework 2004-2014 next steps. March 2006.*
[5] *PSA target metrics for the UK research base OST 2004*
[6] *Science and Innovation investment framework 2004-2014 July 2004*

level in those areas that are key to defence capability and national competitiveness. We now need to work together to develop this template in collaboration with industry and the university sector to ensure the UK maintains a strong research base in these areas.

Our R&D programmes must be vibrant, inventive and innovative. We want to stimulate and nurture an environment of innovation to create new and effective science and technology solutions, identify the approaches that look most promising, and drive early exploitation onto the front line. The civil sector is increasingly becoming a significant source of science and technology; we must access this, grasp the opportunities it presents and adapt them quickly and effectively into defence benefit. Equally we must look to exploit those opportunities to transfer defence technologies into the civil sector. One example of this is the contribution that naval sonar technologies have made to medical ultrasound.

Science and technology based defence R&D provides a highly stimulating environment for those who really want to make a difference. Those who have chosen this path have stimulating and rewarding professional lives. We need to work with the most capable scientists and engineers in government, industry and the universities, supporting the wider national effort in stimulating a greater desire for careers in science and engineering amongst our very best people.

Working with our allies at many levels is vital to address our common challenges effectively. This is particularly true with science and technology research. This DTS maps out those areas where we believe research collaboration can deliver the greatest benefit.

This strategy has been developed by drawing together experts from across MOD, wider government, the defence industry and academia. The task has been demanding, but the result reflects the commitment and enthusiasm of all those involved, and I am extremely grateful for what they have achieved. Without doubt a major step forward, it identifies the actions the defence sector must take to maintain an appropriate level of R&D investment in those areas key to defence capability and national competitiveness.

It is now vital that we work together to deliver this strategy to ensure the UK maintains a strong research base in the areas identified as critical to our security and sovereignty.

MINISTRY OF DEFENCE

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The Challenge

1. Today the UK faces adversaries whose tactics change rapidly and employ ever more varied advanced and innovative technologies. This demands rapid evolution in our response, both tactically and in the technologies we deploy to combat the threats. We must therefore continuously examine the balance and quantity of our research and development (R&D) investment to meet these changing circumstances.

2. Scientific understanding and the technologies that emerge from this improved knowledge are growing at an ever increasing pace and offer a wide diversity of solutions to this evolving threat environment. Our task is to anticipate, prepare and meet the forthcoming challenges by being highly innovative, agile and flexible in our approach to defence science and technology based R&D. This must be complemented by rapid exploitation to yield military advantage with an ever increasing tempo.

3. As promised in the Defence Industrial Strategy (DIS)[1] we have reviewed our approach to R&D. Through this Defence Technology Strategy (DTS) for the first time MOD openly publishes its priorities for R&D, funding, skills, improved processes, opportunities and areas for international research collaboration. The key findings and major initiatives we will undertake are as follows.

Key Findings

- Current threats emphasise that science and technology is fundamental to UK military capability.
- Need for greater combined MOD and industry investment in R&D with more emphasis on research.
- MOD overemphasises the maturing of current technologies to the detriment of the new.
- Industry investment in defence R&D is low compared with that of MOD.
- World class research skills and science & technology expertise are essential.
- MOD must own and control key technologies e.g. C4ISTAR system of systems architecture.

Major Initiatives

- Grand challenges.
- Competition of Ideas.
- Increase emphasis on science and technology based research.
- Engage with industry on its future investment in defence R&D.
- Invest in skills:
  - Increase emphasis within Dstl on depth of science and technology expertise
  - Royal Society Postdoctoral Research Fellowships pilot scheme for up to 3 researchers
  - Doctoral research pilot scheme for up to 30 students

4. This document sets out the following key information:

- The priority science and technology areas for R&D investment.
- The critical areas where we are dependent upon the viability of UK science and technology for operational sovereignty and security.
- Clear opportunities for collaboration with industry, University sectors and international allies.
- Where we must adapt and integrate within the UK those military sub-systems and components bought elsewhere.
- Where we must maintain intelligent customer expertise in order to operate a viable strategy of purchasing COTS products.
- New initiatives to stimulate innovation in defence research.
- Actions MOD and industry must take to drive forward and exploit the defence science and technology based defence R&D programme.
- How to support further the skills base in science and engineering within the UK to provide for both MOD and the defence industry sectors.

5. This Defence Technology Strategy (DTS) is unclassified permitting the widest possible distribution as a catalyst for stakeholder action. The MOD is involved in a broader range of science and technology areas than is covered in this report and, by necessity, the DTS is a balance of detail versus security. In order to release an unclassified document to industry and academia, it has been necessary to exclude technology details in sensitive and classified areas.

[1] *Defence White Paper: Defence Industrial Strategy Cm6697, dated December 2005.*

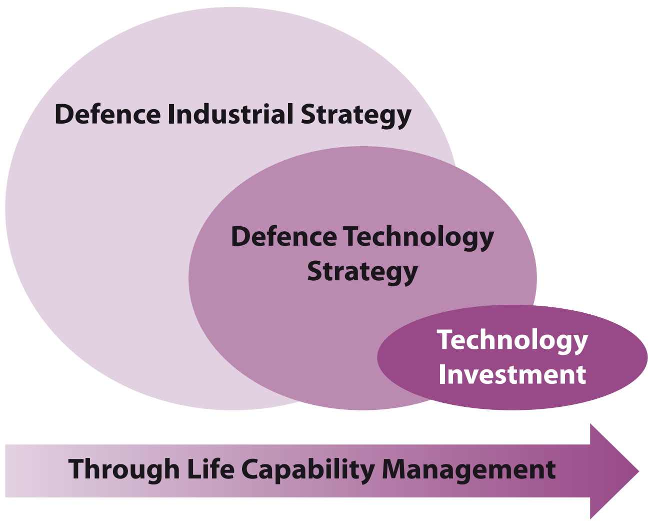

Fig 1. Stages in Delivering Technology Component of TLCM

6. The DTS addresses science and technology priorities spanning research through development and ultimately exploitation, and is being developed at a time of great change. For the DTS to remain effective it needs to be flexible and responsive as the threat and technology changes. Future updates will be produced approximately every 2 years to address these changes.

Delivering The DTS

7. Effective delivery of the DTS comprises 4 key components:-

- Science and technology priorities.
- Delivery process to speed up R&D exploitation.
- Joint MOD/industry framework for investment.
- Working closely with Dstl and the universities to support defence science and technology.

These are underpinned by 2 critical enablers:

- A well documented supply chain that stimulates and exploits innovation.
- Investment in science and engineering skills of relevance to defence technologies.

Science And Technology Priorities

8. The DTS examines defence Science and Technology (S&T) priorities in great detail, giving clear statements of MOD's intentions related to over 200 major categories of science and technology, with further detail below each of these categories.

9. The key actions are detailed in Section C. However, certain areas of S&T require particular attention either because we need to increase our resilience to a threat, or because not doing so would lose an advantage. Topics falling into this category where MOD, including Dstl will work with industry and universities include:

- Advancing S&T in:
  - Man-portable biological detection systems.
  - Radar, because it remains our most important sensor.
  - Modular open systems, as a key enabler for TLCM and technology insertion.
  - Modelling and simulation and related data collection for improved military capability and to enable us to learn from experience.
  - Propulsion (TLCM and novel systems).
  - Generic medical countermeasures.
  - Satellites for information collection and analysis.
  - Gallium Nitride circuit technology.
  - Materials and Structures for protection and through life support.

- Setting up communities of practice[2], in core technologies that will continue to shape future capability delivery in:
  - Signal and data processing.
  - Geolocation and synchronisation.

- Increasing innovation and national capability in critical areas by creating university centres of excellence in areas such as:
  - Sensors.
  - Technologies to support C4ISTAR.

Delivery Process to Speed Up R&D Exploitation

10. A major factor that has hindered the speediest exploitation of R&D is having only a limited definition of an end-to-end process engaging all the key stakeholders (i.e. the S&T staff within MOD, the Equipment Capability Customer, Defence Procurement Agency, Defence Logistics Organisation and industry). Much valuable work has been undertaken by MOD and industry on this issue. Specifically, the Technology Maturation Study[3] identified the need for Through Life Management Plans underpinned by joint MOD/industry planning and roadmapping using agreed metrics such as Technology Readiness Levels[4]. MOD will ensure that a planning process is in place involving key MOD and industry stakeholders based on technology roadmaps, to address quality and relevance using independent peer review **by September 2007.**

11. The most challenging research problems facing MOD are those where there are no known solutions,

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[2] The concept of a community of practice (often abbreviated as CoP) refers to the process of social learning that occurs when individuals who have a common interest in some subject or problem collaborate over an extended period to share ideas, find solutions, and build innovations.
[3] Findings of the 3 Technology Maturation Study, presented at a joint MOD/industry Workshop entitled 'Managing Research under Output Ownership' held on 28th May 2004 at the Defence Procurement Agency, Abbey Wood, Bristol.*
[4] http://www.ams.mod.uk/ams/content/docs/trl_guide/trlguide.pdf

or where solutions need to be more affordable and the current approach does not lend itself to significant cost reduction within the necessary performance envelope. Therefore we need to stimulate innovation for these most challenging of problems. Critical to success will be the early identification of promising approaches and termination of the less promising ones. We will drive those most likely to provide significant defence benefit hard through to exploitation.

12. This approach is most important when seeking solutions to the most demanding problems encountered on current operations. MOD is making research support to operations a key component of its revised approach to delivering research (establishing a new research output structure is an action from the Enabling Acquisition Change[5] programme). This will include a fast-track approach to demonstrating proof of principle enabling the earliest exploitation in theatre, a description of which will be complete **by December 2006.**

Joint MOD/Industry Framework For Investment

13. The DTS takes the DIS forward, giving greater emphasis to through life capability issues. Analysis has assumed that MOD will, as now, advance technologies to an intermediate technology readiness level (TRL) for the majority of topics showing significant potential. However, driving technologies through to a mature state, particularly TRL 6 and up will require significant industrial funding.

14. Against this background, the DTS is affordable provided both MOD and industry invest together, but there is much work needed on this.

15. Recent analysis[6] has shown that there is a correlation between the quality of military equipment and the funding by governments in Defence R&D. Funding is important in terms of overall level, balance between longer term research and shorter term development, and also timing with respect to exploitation. Furthermore, the balance between MOD and industry funding, and at which stages the funding is needed from each is also important.

16. The position of industrial funding of defence R&D needs to be contrasted with industrial R&D funding in the civil sector. By way of example[7], the level of UK aerospace industry self-financed R&D in the civil sector in 2005 was approximately 6% of its £10.5Bn turnover. However, its self-financed R&D in the defence sector was only approximately 2% of its £12.2Bn turnover. This should be compared with the UK MOD's total R&D investment of over 8% of the defence budget.

17. Furthermore, the UK aerospace sector only spends 8% of its total R&D budget on research.

18. By way of comparison[8] between UK R&D funding for defence and for the civil and defence sectors combined, the UK Government national target is to increase R&D investment from the 2005 figure of 1.9% (£22Bn) to 2.5% of GDP by 2014. Looking at civil and defence combined (which is dominated by civil), of the 1.9%, business enterprise (industry) is contributing slightly over 1.1% of the 1.9% (i.e. HMG is contributing 0.8%). As HMG increases its R&D investment to meet the 2014 target, it is looking to business enterprise (industry) to play its part. It is important to note however, whilst overall industry does invest in R&D, defence industry investment is low.

19. It is recognised that substantial industrial investment in defence R&D might be difficult for the more inventive and innovative research which can be characterised as high risk, albeit potentially high pay-off. However, once the science has been established, and ideas turn towards more applied research and on to development and demonstration, industry will need to make an increasing contribution. At the more applied stages of R&D, wider considerations (e.g. the practicality of productionising a technology at an affordable and competitive price) begin to play a larger part in determining suitability for exploitation, hence a larger industrial financial input is appropriate.

20. In addition to considerations of levels and partitioning of funding, it is crucial that all those involved in R&D must increase their efforts to demonstrate value and benefit from such investment, recognising that most of the spend today influences capability in future decades.

21. The issue of research, and R&D funding, requires wide debate in the coming months, both within MOD and more broadly across wider government and industry and should be a major agenda item for the NDIC beginning **Autumn 2006.**

22. Figure 2 illustrates the model showing how overall cost (from research to manufacture) grows through the maturation process, the key S&T suppliers at each stage, and the balance of funding between MOD and industry that reflects technical risk reduction and increasing potential commercial benefit.

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[5] *Enabling Acquisition Change: An examination of the MOD's ability to undertake TLCM – dated June 2006*

[6] *'The Effects of Defence R&D on Military Equipment Quality', Middleton, Burns et al., Defence and Peace Economics Apr 2006.*

[7] *All Aerospace data taken from the SBAC's UK Aerospace Industry Survey 2006 (http://www.sbac.co.uk/pages/53339785.asp)*

[8] *OECG Economic Surveys –UK Vol 2005/20 November 2005 Supplement No. 2, ISBN 92-64-01411-X.*

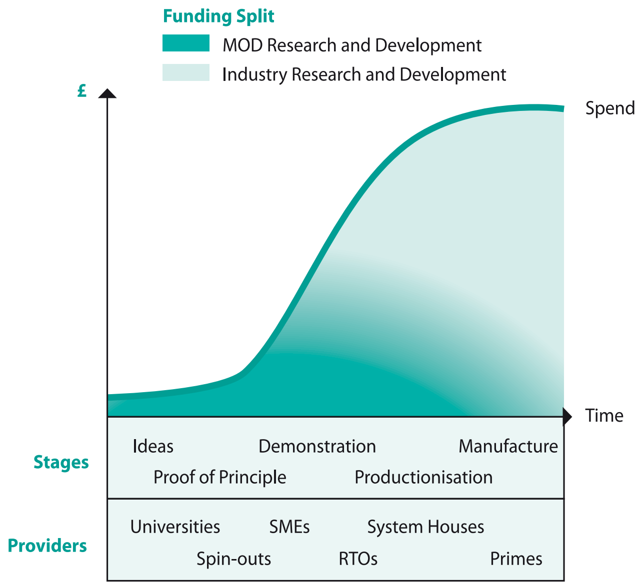

Fig 2. Science Innovation Technology Maturity Model

23. It is important to note that international research collaboration, which offers significant financial gearing when well planned and targeted by the collaborating partners, will be a major contributor to the successful outcomes of R&D where such collaboration is appropriate.

Working Closely Through Dstl with the Universities to Support Defence Science and Technology

24. Dstl is the MOD's principle internal source of scientific and technological expertise. It has a particular role in undertaking research, supporting development and giving broad science and technology advice, particularly in areas that must be retained within government.

25. As such, it is vital that Dstl retains and develops the S&T skills necessary to fulfil its role. This will be done by a combination of undertaking high quality research in-house, and in working closely with MOD's research suppliers, particularly the universities.

26. Furthermore, since Dstl has a key role in helping ensure the MOD has access to skilled scientists and engineers, including supporting recruitment, it is particularly important that Dstl develops a close and effective relationship with the universities.

A Well Documented Supply Chain That Stimulates and Exploits Innovation

27. A major factor affecting defence achievement of the benefits of S&T through R&D is the stimulation, nurturing and exploitation of invention and innovation.

28. Innovation in military equipments contributes to achieving a battle-winning edge by giving a technological advantage over opponents. The DIS committed MOD to develop a better understanding of the innovation process, to enable better, faster pull-through of new technology into military capability. In support of this, the NDIC (R&T) Sub-Group tasked key industrial partners to map technology trees for a wide range of military equipments. These technology trees have been produced and are providing a most useful insight into our supply chains and the contributions that different players make. The NDIC(R&T) Sub-Group will issue its innovation report in **Autumn 2006.**

29. MOD wishes to create a 'DARPA' like effect[9] within its R&D programme. The key characteristics of DARPA that MOD wishes to capture are the ability to stimulate potentially highly innovative and inventive ideas, and to drive the ones that show real promise hard to earliest exploitation. MOD will produce options for achieving a DARPA effect as part of delivery of the EAC study[10] **by December 2006.**

30. A major step forward will happen when MOD puts in place a 'Competition of Ideas' process to expose and seek solutions to defence problems that need innovation and injection of new ideas from a wide range of potential suppliers. This is expected to appeal particularly to universities, SMEs and Research and Technology Organisations, as well as other lower tier suppliers. The scheme, which will have an initial kick-start budget of £10m, (but which will be reviewed in the light of the initiative's success in stimulating novel ideas) will be operational from **Autumn 2006.**

31. MOD will also launch a 'grand challenge' competition to provide the best solution to a defined capability need. This initiative is part based on DARPA's concept[11], most recently focused on autonomous land vehicles to transit a desert terrain, which has been very successful in both attracting many high quality research teams, and in generating innovative solutions. MOD's first competition will be initiated in **November 2006.**

32. As part of stimulating good research proposals from across the S&T research community, MOD is increasing the proportion of its research programme to be competed to around 60% **by 2009/10[12].**

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[9] *Defense Advanced Research Projects Agency Home Page (http://www.darpa.mil/)*

[10] *Enabling Acquisition Change: An examination of the Ministry of Defence's ability to undertake Through Life Capability Management – dated June 2006*

[11] *DARPA Grand Challenge website (http://www.darpa.mil/grandchallenge/index.asp)*

[12] *NAO report Management of Defence Research and Technology 10 March 2004 (note this refers to what were applied or corporate elements of the research programme which formed the QinetiQ assurance and not the whole research programme).*

Investment in Science and Engineering Skills of Relevance to Defence Technologies

33. The DIS[13] identified the importance of the science and engineering skills base in the UK. A recent report by the Department for Education and Skills[14] shows a steadily declining number of Engineering and Physical Science entrants to higher education. The MOD, in partnership with industry, universities and professional organisations is committed to encouraging more students to courses of relevance to defence S&T.

34. We are launching two new 1-year pilot initiatives, which will be reviewed after the first year:

- A Doctoral research scheme to be run in partnerships between Dstl, the defence and technology companies and interested universities, in engineering and scientific fields of high importance to defence, to appoint up to 30 students **starting Summer 2007**
- Working with the Royal Society to identify candidates for up to 3 postdoctoral research fellowships **by Winter 2006**

35. In addition, we need to have the requisite leadership, acquisition and technical skills to be able to formulate requirements, undertake and exploit R&D. Hence, to achieve better delivery of our programmes and projects and more effective Through Life Capability Management (TLCM), we will, working with industry and the universities, develop a skills programme. This will involve a complete analysis of our science and engineering skills needs, culminating in improved training and development plans, definition of professional standards, skills "footprints" and the requirements for accomplishments such as licences **during 2007**.

DTS: Layout

36. The DTS is structured in three parts:

Section A looks at the strategic context for defence S&T and the areas derived from Defence policy and strategy where R&D programmes are vital to keep the Armed Forces ahead of the ever-more-complex threats they face.

Section B looks at the individual S&T areas in detail, following the topic areas laid out in the 2005 Defence Industrial Strategy, setting priorities and identifying actions.

Section C looks at how the MOD, working with industry, academia and other stakeholders will proceed with implementation of the DTS, setting time lines vital for the successful delivery of defence needs.

DTS: The Core

37. Section B is the core of this DTS. It is in this section that all stakeholders concerned with defence S&T, be they parts of the MOD, in academia, industry, or international collaborators, can find the necessary level of detail about the overall strategy. We list those areas of S&T which the MOD requires access to within the UK industrial base, or where MOD must retain understanding or control.

38. We have addressed the need for sustainment of critical S&T capability and scientific and technical expertise, and recognised the need for innovation and technology development to meet emerging and future defence needs.

39. This DTS identifies MOD's current science and research baseline, and where it plans to be in the future, so that all stakeholders can understand the task at hand and shape their plans accordingly. In the past, too often, information and intentions have not been shared with the wider defence community, and this has subsequently led to problems.

40. Following the DIS, Section B is broken down into 9 specific chapters which mark the key science and technology areas that will drive and exploit defence R&D, plus an additional 2 covering generic areas*:

- *Cross-Cutting Technologies.
- Command, Control, Communications, Computers, Intelligence, Surveillance, Target Acquisition and Reconnaissance (C4ISTAR).
- Close Combat and Combat Support.
- Chemical, Biological, Radiological and Nuclear (CBRN).
- Counter Terrorism.
- Complex Weapons.
- General Munitions and Energetics Technologies.
- Fixed Wing and Unmanned Aerial Vehicles (UAVs).
- Helicopters.
- Maritime.
- *Emerging Technologies.

41. In each chapter we have identified S&T areas that are a priority focus for our investment, defined the level of national capability requirement we need to support the appropriate sovereignty needs of the DIS[15], and indicated those areas we believe collaboration will be most beneficial for meeting those needs. A national capability requirement does not mean we will not engage in international research collaboration on these topics; whilst we are open to collaborate on them, we will only do so if it does not compromise UK's operational independence. The analysis approach used in deriving the results of Section B is shown in Figure 3.

[13] *DIS, Section B1 xvi ff.*

[14] *The Supply and Demand for Science, Technology, Engineering and Mathematics Skills in the UK Economy, Research Report RR775, 2006.*

[15] *DIS, Sect A1.21-22*

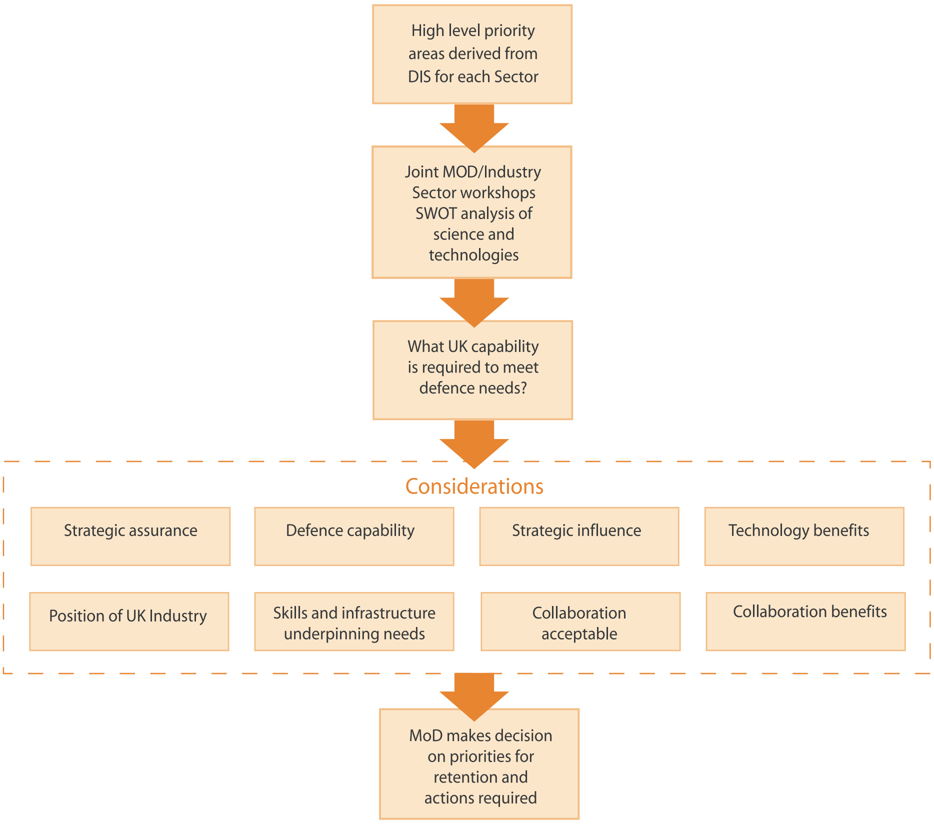


Fig 3. DTS Technologies Assessment Process

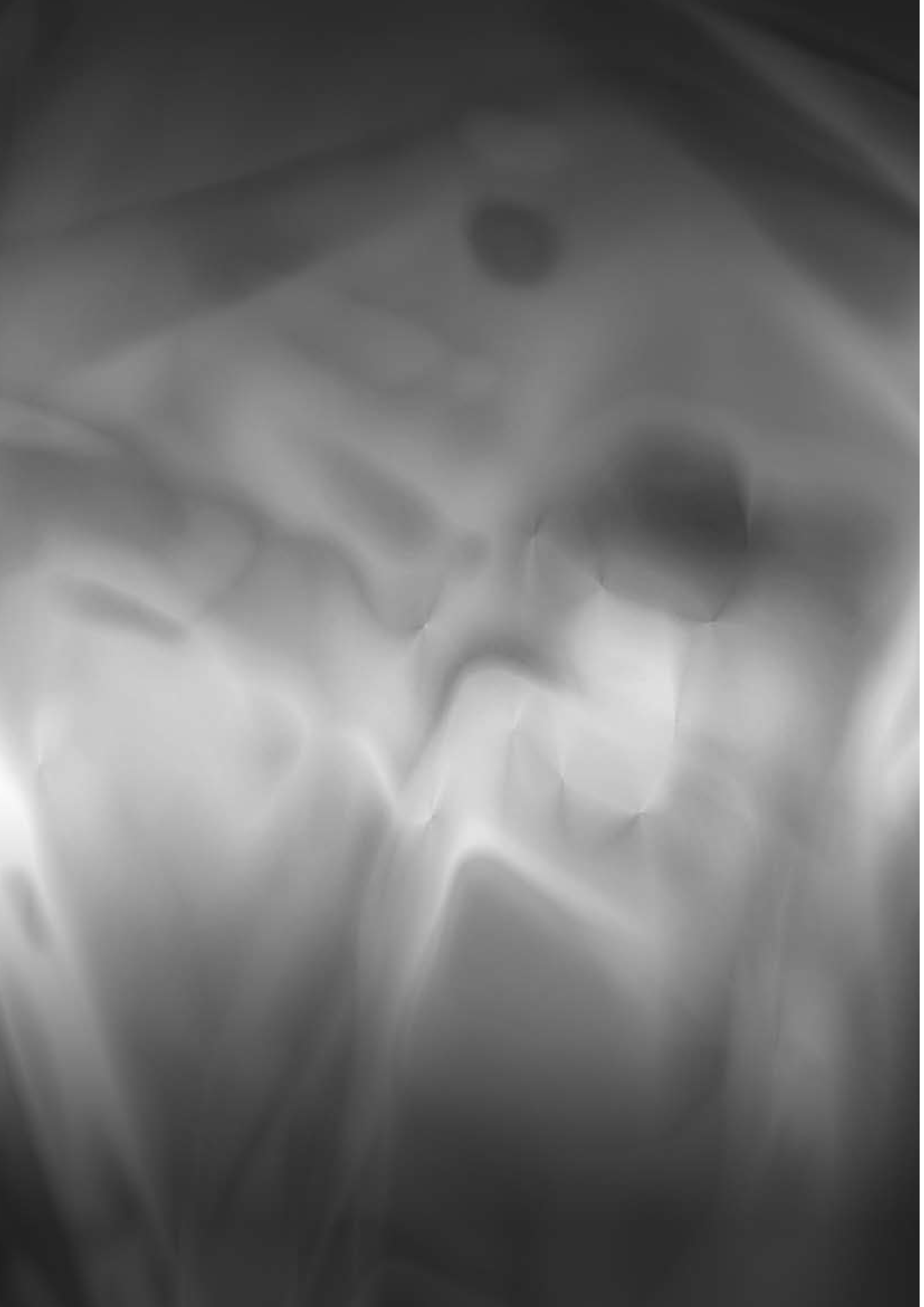
Implementation

42. We have set out the strategic vision of the UK's defence R&D requirements over the next 10 years. It provides a better understanding of where the MOD will invest and those areas of national importance that should be nurtured and maintained. We have highlighted those areas that will underpin our Through Life Capability Management. The task we now face is to build on this planning and work together to:

- Sustain vital defence S&T in the long term by harnessing all parts of the research and development chain through government, industry, academia and where there is mutual advantage with our key allies;
- Develop a coherent structure and process to ensure S&T requirements are defined and pursued effectively;
- Create structures within the R&D programme that are capable of flexible and rapid responses to the changing defence environment, and develop processes and architectures that allow rapid technology insertion;
- Build on existing and develop new joint working practices to fulfil and deliver the R&D programme and to exploit R&D to deliver world class military capability.

Introduction

section **A**



A1 Purpose and Scope

A1.1 Today, the UK faces adversaries who rapidly change their tactics and employ ever more varied, advanced and innovative technologies. Never has there been greater uncertainty in the nature of the threat faced by the UK, nor has that threat adapted and changed so rapidly. This demands rapid evolution in our response, both tactically and in the technologies we deploy to combat the threats. We must therefore continuously examine the balance and quantity of our Research and Development (R&D) spend to meet these changing circumstances, taking a through-life view across all Defence Lines of Development (DLOD), and also of the balance between them, where well managed and directed research and development plays a vital role.

Defence Lines of Development

- Training
- Equipment
- Personnel
- Information
- Concepts and doctrine
- Organisation
- Infrastructure
- Logistics

A1.2 Scientific understanding and the technologies that emerge from this are growing at an ever increasing pace offering a wide diversity of solutions to this evolving threat environment. Our task is to anticipate, prepare and meet the forthcoming challenges by being highly innovative, agile and flexible in our approach to defence science and technology research and development. This must be complemented by rapid exploitation to yield military advantage.

A1.3 To ensure that the critical technologies are identified and developed it is essential that we take a strategic approach to our R&D programme. Whilst the Defence Industrial Strategy (DIS) provided an initial analysis of technology needs on a sector by sector basis it recognised that we also must change the way in which we determine R&D priorities and deliver against them. Critically, there must be greater focus on MOD's core needs, a clear emphasis on Through Life Capability Management (TLCM) and comprehensive engagement between MOD, our collaborative partners and our technology supply base.

A1.4 The DIS provided greater transparency of MOD's future defence requirements and, for the first time, set out those industrial capabilities needed to ensure we can operate our equipment in the way we choose. The DIS also committed us to an update of the previous MOD Technology Strategy[1] , which provided the department's guidance on relative science and technology research priorities at that time.

A1.5 This Defence Technology Strategy (DTS) provides that substantial update and for the first time openly publishes MOD's priorities for R&D, investment, skills, delivery process, and the role and areas for international research collaboration. The MOD is involved in a broader range of R&D areas than is covered in this report and, by necessity, the DTS is a balance of detail versus security. In order to release an unclassified document, permitting the widest possible distribution as a catalyst for stakeholder action, it has been necessary to exclude technology details in some sensitive and classified areas.

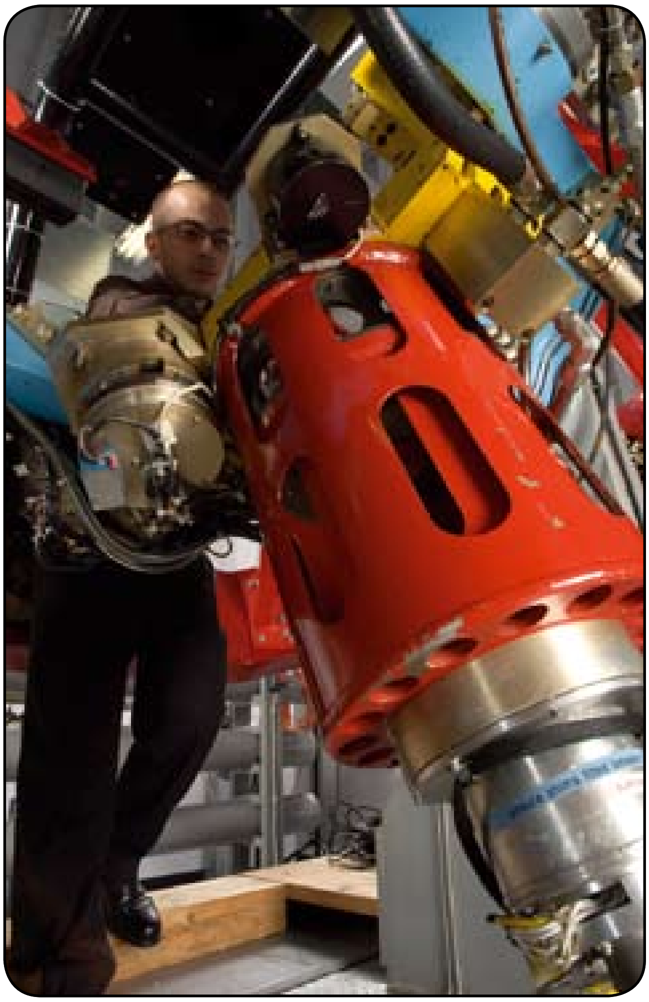
Testing of new weapon concepts - 'Cornershot'

A1.6 This document sets out the following key information:

- The priority sciences and technologies on which we must focus our research and development investment.
- The critical areas where we are dependent upon the viability of UK science and technology for operational sovereignty and security.

[1] *MOD Technology Strategy: Priorities for Defence Research [UK Restricted] dated May 2005.*

- Clear opportunities for collaboration that we must take advantage of with the industry and university sectors and also with our international allies.
- Where we must adapt and integrate within the UK those military sub-systems and components bought elsewhere.
- Where we must maintain intelligent customer expertise in order to operate a viable strategy of purchasing commercial-off-the-shelf (COTS) products.
- New initiatives to stimulate innovation in Defence research.
- The specific actions MOD and industry must take to drive forward and exploit the Defence research and development programme.
- How to further support the skills base in science and engineering within the UK to provide for both MOD and the defence industry sectors.



Missile simulation facility

A1.7 The DTS addresses crucial science and technology priorities spanning research through development and ultimately exploitation. The Defence science and technology community will need to remain highly flexible and responsive, as scientific understanding and technology changes, to be effective. The DTS provides an initial critical analysis of research priorities; it continues that analysis into essential development priorities for the sectors described in the DIS. The vital key has been to bring together research and the essential sector priorities with improvements to ways of working in a TLCM context. This version of the DTS provides the necessary foundations for joint planning, in line with the DIS goals, which MOD and industry will continue across all the sectors.

Examples of benefits research and development investment has brought to military capability:

- thermal imagers giving long-range and night time combat advantage to our forces;
- bomb disposal devices which are key to protecting UK service personnel in Iraq;
- the Thermal Imaging And Laser Designation (TIALD) pod for precision targeting;
- counter terrorism technologies – now co-ordinated by the new MOD Counter Terrorism Science and Technology Centre;
- medical research (including a blood clotting drug) which has reduced loss of life and improved recovery rates;
- quicker and safer decontamination of vehicles exposed to chemical warfare agents;
- protection of military aircraft from enemy air-defence assets;
- the Joint Strike Fighter flight propulsion control system to make carrier landings easier and safer;
- stealthy materials such as tiles for acoustic stealth on our nuclear submarines;
- improved respirators, detectors and vaccines to protect our troops from chemical and biological attack;
- urban warfare research has provided the ability to explore numerous scenarios for current operations;
- a wide range of Operational Analysis (OA) studies have saved the MOD billions of pounds.

A2 The Impact of Research Funding on Military Equipment Quality

A2.1 Recent analysis[1] has shown that there is a correlation between the quality of military equipment and the investment by governments in Defence R&D. Indeed, the only strong factor affecting equipment quality is absolute R&D spend (not a fraction of defence budget, overall defence budget nor number of equipments bought). The graph at Figure 1 was published in the DIS, showing that we now have the ability to predict the future equipment quality that UK might face in combat, as a function of time and national investment level.

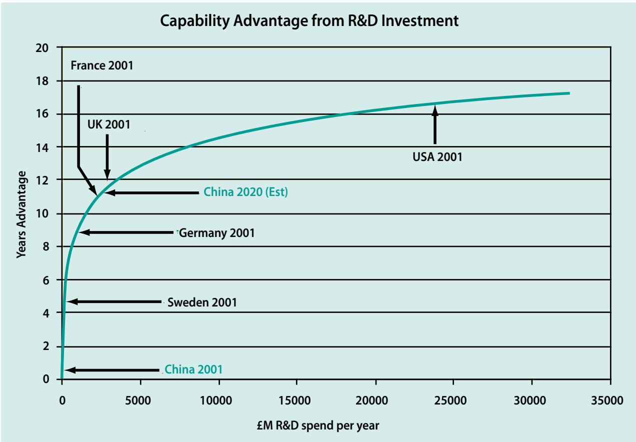


Figure 1 - Relative Years Advantage in Equipment Quality as a Function of R&D Spend per Year

Apache, a potent new military capability

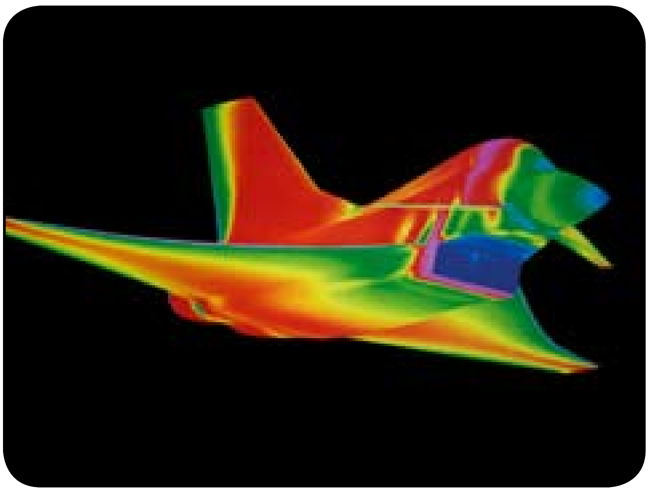
[1] *The Effects of Defence R&D on Military Equipment Quality', Middleton, Burns et al., Defence and Peace Economics Apr 2006.*

A2.2 Figure 1 shows, for example, that UK military equipment in 2001 taken as a whole, was on average 12 years more advanced than that of China's in the same year. The estimated position for the UK in 2020 is based on assuming R&D levels are broadly maintained, whilst that for China assumes a continuation of its growth in R&D investment. It also assumes that the predictive formulae hold out to that period. Note that the countries studied include those that invest strongly in indigenous equipment capability as well as those that use a more modest level of R&D investment to be intelligent customers and provide some degree of local modification of foreign equipment bought.

A2.3 The analysis has shown that the advantage achieved at any one time depends on the R&D investment made over the previous 25 years. In particular, investments 5 and 20-25 years earlier are critical, corresponding to development activity (about 5 years earlier) and defence research activity (typically 20-25 years earlier). Clearly advantage can be gained or lost by increasing or decreasing R&D investment relative to other R&D investing nations.

A2.4 We can expect UK forces to face opponents armed by the major exporting nations, and we can now predict how good opponents' equipment will be relative to our own. Hence the challenge for the UK is to determine the appropriate level of R&D investment in order to achieve its defence aspirations.

A2.5 Investment is therefore important in terms of overall level, the balance between longer term research and shorter term development, and also the timing with respect to exploitation. Furthermore, the balance between MOD and industry investment, and at which stages it is needed from each is also important.



Drag co-efficient modelling for Typhoon

A2.6 The position of industrial funding of defence R&D needs to be contrasted with industrial R&D funding in the civil sector. By way of example[2], the level of UK aerospace industry self-financed R&D in the civil sector in 2005 was approximately 6% of its £10.5Bn turnover. However, its self-financed R&D in the defence sector was only approximately 2% of its £12.2Bn turnover. This should be compared with the UK MOD's total R&D investment of over 8% of the defence budget.

A2.7 Furthermore, the UK aerospace sector only spends 8% of its total R&D budget on research.

A2.8 By way of comparison[3] between UK R&D funding for defence and for the civil and defence sectors combined, the UK Government national target is to increase R&D investment from the 2005 figure of 1.9% (£22Bn) to 2.5% of GDP by 2014. Looking at civil and defence combined (which is dominated by civil), of the 1.9%, business enterprise (industry) is contributing slightly over 1.1% of the 1.9% (i.e. HMG is contributing 0.8%). As HMG increases its R&D investment to meet the 2014 target, it is looking to business enterprise (industry) to play its part. It is important to note however, whilst overall industry does invest in R&D, defence industry investment is low. It is thus crucial that all those involved in R&D must increase their efforts to demonstrate value and benefit from such investment, recognising that most of the spend today influences capability in future decades.

Experiment using an Argon laser

A2.9 It is recognised that substantial industrial investment in defence R&D might be difficult for the more inventive and innovative research which can be characterised as high risk, albeit potentially high pay-off. Thus MOD recognises that it must take the lead in this area; once the science has been established, however, and ideas turn towards more applied research and on to development and demonstration, industry will need to make an increasing contribution. At the more applied stages of research and development, wider considerations (for example, the practicality of productionising a technology at an affordable and competitive price) begin to play a larger part in determining suitability for exploitation, hence a larger industrial financial input will be appropriate.

A2.10 The issue of research and R&D investment requires wide debate in the coming months, both within MOD and more broadly across wider government and industry.

[2] All Aerospace data taken from the SBAC's UK Aerospace Industry Survey 2006 (http://www.sbac.co.uk/pages/53339785.asp)

[3] OECG Economic Surveys –UK Vol 2005/20 November 2005 Supplement No. 2, ISBN 92-64-01411-X.

A3 Strategic Context

A3.1 The MOD's primary strategic direction is provided by the Department's Defence Strategic Guidance (DSG). This defines detailed defence planning assumptions, including priorities for resource allocation and capability development. The DIS provides greater detail of the capability requirements expressed by DSG, indicates ways in which these may be met and highlights those important industrial capabilities that must be retained in the UK for operational sovereignty and national security reasons.

A3.2 The DTS details the overall research, and in many cases development, priorities defined in DSG and captures the more detailed science and technology priorities that arise from the DIS. It is further informed by the Capability Area Plans (CAPs) produced by the MOD; these highlight particular current and future capability gaps. MOD planners and managers will therefore be steered by DSG, DIS, CAPs and DTS when formulating and placing their capability delivery and R&D programmes. The guidance provided by these documents will influence both the priority areas for investment and the balance of investment between those areas.

A3.3 As these strategic documents clearly demonstrate, we face a future which is less certain, and more rapidly evolving, than even the recent past. More "traditional" threats from potentially hostile states now sit alongside increasing threats from non-state actors. This is a driver for change within defence R&D. Both types of threat are likely to be asymmetric, requiring us to innovate, develop and adapt our defence capabilities to anticipate the changing threat and to be rapid and flexible in our response. Science and technology research and development are central in meeting these demands.

A3.4 The management of our R&D has changed over time, with greater emphasis today on the Armed Forces, as the customer, being best placed to define these needs. However, with the ever increasing pace of technological change, we must keep in mind that the customer may not always be best placed to decide what new and emerging technologies have the potential to solve a capability requirement. The expert scientist or engineer who works at the forefront of a research field must always be an integral part of deciding what new technologies offer potential solutions. With this in mind, our R&D spend must always nurture innovators at the front of their fields, whether they be in universities, industry or government agencies. The challenge for the MOD is to decide on the proportion of R&D spend devoted to basic research to foster innovation, and that on the development of defence capabilities based on existing technologies.

UK Defence priorities and capability gaps

Defence Strategic Guidance (DSG) provides the principal strategic direction for the development of defence and the policy baseline for the MOD's planning cycle. It provides detailed defence planning assumptions, including priorities for resource allocation and capability development, stretching out broadly over the next 15 years.

The key challenges for MOD, as defined by DSG, include:

- Delivering UK defence capability
- Countering International Terrorism
- Reducing the threat of WMD (encompassing CBRN weapons)
- Fostering a stable international environment
- Reducing the threat from failed and failing states
- Operating within a sound legal framework
- Maintaining energy security
- Understanding the effect on operational environments from climate change

DSG also identifies the following critical enablers to meet these challenges:

- Ensuring the Armed Forces are capable, motivated and equipped to counter the most likely threats
- Managing the MOD efficiently and effectively
- Delivering sufficient numbers of appropriately skilled service and civilian personnel
- Enhancing the competitiveness and sustainability of UK Defence industry while continuing to provide the UK Armed Forces with high quality and best value for money equipment
- Maintaining a strong UK Defence S&T capability which will allow us to retain a technological and capability edge over our likely adversaries

DSG includes, within its Future Capabilities Development section, direction on research priorities. These priorities drive the formation of the Capability Area Plans (CAPs), which are authoritative statements of capability surpluses, shortfalls and future development plans in each equipment capability area. The capability gaps identified in the CAPs have driven the science and technology priorities identified in the DIS and detailed in the DTS.

A3.5 The changing threat itself can often be driven by advances in science and technology and evidence to support this grows as the internet facilitates the rapid diffusion world-wide of technological information. However, science and technological progress can also present innovative new ways of meeting defence capability requirements. This is also a driver for defence R&D. It is therefore vital that we monitor science and technology developments, to target research at areas of relevance and develop innovative new ways of meeting our defence capability requirements.

A3.6 A further driver for change is the considerable reorganisation and consolidation which has been taking place within the defence industrial base in recent years.

A3.7 These drivers are set against the pivotal requirement to deliver defence capability in an effective and affordable fashion but with a firm commitment to speedy exploitation for current operations. We have recently launched a number of initiatives within the department, such as rapid assistance to operations, the MOD Counter Terrorism Science & Technology Centre[1], the Defence Technology Centres (DTC)[2] and Towers of Excellence (ToE)[3], all aimed at developing a better understanding of the critical capabilities we require and the ways in which they can be most effectively delivered.

MOD Counter Terrorism Science & Technology Centre

The MOD Counter Terrorism Science and Technology Centre was created to respond to the increasing terrorist threats facing the UK and our Armed Forces.
The Centre acts as the hub for UK MOD Counter Terrorism (CT) Science and Technology (S&T) research. It facilitates innovation and problem solving, delivering rapid solutions to ensure that the best science underpins MOD's and, more broadly, the Government's response to the threats posed by terrorism.
The Centre actively seeks S&T collaboration with national and international partners, in academia, industry and government to work together in the global fight against terrorism.

X-ray imaging

1 *http://www.ctcentre.mod.uk/*
2 *http://www.science.mod.uk/pages/dtc.htm*
3 *Towers of Excellence, www.mod.uk/toe.*

Defence Technology Centres

The success of the Defence Technology Centres (DTCs) is clear evidence of the benefits of using a partnering approach to develop critical technologies for key topics in defence. The DTCs are jointly funded by MOD and industry consortia, with MOD earmarking approximately £90M over a five year programme to support four DTCs. DTCs work with a wide range of suppliers, including SMEs and academia, to identify new technologies and innovation where MOD and industry investment is likely to produce significant benefit. A further characteristic of DTCs is a flexible management approach that allows an effective response to different situations and emerging needs and priorities. There are four Defence Technology Centres:

Electro Magnetic Remote Sensing (EMRS) – innovative and cost-effective sensor technologies in any part of the EM spectrum to detect and/or identify and/or locate targets at longer range and in adverse weather. Applicable to air, land, sea or space-based sensing systems. www.emrsdtc.com

Data and Information Fusion (DIF) – technology, architectures and implementations to provide timely critical information through a more integrated network approach to command and control. www.difdtc.com

Human Factors Integration (HFI) – technologies to support defence capabilities and to allow systems to be designed around people rather than people adapting to or working around poor environments. www.hfidtc.com

Systems Engineering for Autonomous Systems (SEAS) – innovative technologies relevant to autonomous systems, using Systems Engineering approaches to encourage pull-through of the technology into military capabilities. www.seasdtc.com

Towers of Excellence

In the 1998 Strategic Defence Review White Paper, the UK Government made clear its commitment to a strong and healthy UK defence industry, and a commitment to forces equipped with a decisive technological edge in critical capability areas. Towers of Excellence represent an innovative approach to defence technology development with a military system or sub-system focus. They are built upon a new level of co-operation and interaction between the MOD and the UK's leading equipment supplier base. They also draw upon the particular strengths of UK academia.

The Towers of Excellence model is an approach to being selective in a rational way and making the necessary choices in partnership with industry. They are co-operative groupings, led by the MOD, which bring together key players in the UK defence industry sector and leading UK academic establishments. Six priority areas have already been identified:

- guided weapons
- electro-optic sensors
- synthetic environments
- radar
- under water sensors
- electronic warfare

A4 The Role of Dstl

A4.1 The Defence Science and Technology Laboratory (Dstl) is an agency of the MOD. Its aim is to provide independent, high quality scientific and technological services to MOD, the UK Armed Forces and wider Government in those areas inappropriate for the private sector. Its primary purpose is to meet the requirements of its defence customers in the most efficient and cost effective manner. [Dstl also transfers knowledge to defence industries, spins off knowledge for civil application and undertakes collaborative research with other institutions in accordance with MOD policies.] Dstl does not compete directly with industry in any of its activities unless specifically requested to do so by MOD.

A4.2 To fulfil its role, Dstl is required to maintain a high-level overview of science and engineering, be world-leading in areas such as systems and capability engineering advice and engage actively with industry, governmental laboratories and academia.

A4.3 Dstl's work creates the evidence base for major decisions – covering the full range of policy, operational, military capability, scientific and acquisition issues. The agency supports customers in their planning, procurement and risk management activities, and delivers assurance of the science and technology they exploit, as well as exploiting advances in science and technology to deliver practical solutions to defence and security related problems in areas of national and international sensitivity

A4.4 Dstl's wide-ranging expertise is underpinned by an authoritative understanding of defence policy, complete systems and sub-systems and world-class research capabilities. Dstl's unique position in MOD gives it an overview of its customers' problems, across domains and over time, which helps the agency to bring an integrated and coherent approach to programmes. Dstl is therefore, well placed and able to play a full role in developing and implementing many of the actions derived from the DTS.

Decontamination of vehicles

A4.5 Due to the changing nature of MOD's requirements and the challenges this poses to Dstl in allocating effort and resources effectively between competing demands, the agency will continue to vary its output and skill base in line with that requirement and the MOD's strategic objectives to ensure that it remains capable of providing a focussed and efficient scientific and technological service.

A4.6 Furthermore, to ensure its advice is sound and credible, and that it can offer leading-edge solutions to the problems presented to it, Dstl needs to develop and nurture the necessary science and engineering skills. This will be achieved by a variety of methods spanning recruiting established experts, seconding staff to laboratories undertaking high-quality research, right up to undertaking research at the forefront of international effort. Getting the balance correct is challenging and needs careful examination.

A5 Science and Engineering Skills of Relevance to Defence Technologies

A5.1 The DIS[1] identified the importance of the science and engineering skills base in the UK. A recent report by the Department for Education and Skills[2] shows a steadily declining number of engineering and physical science entrants to higher education who will be needed for future Defence R&D. The MOD, in partnership with industry, universities and professional organisations is committed to encouraging more students to courses of relevance to defence science and technology.

Encouraging engineering students, the future of defence needs - Welbeck Defence Sixth Form College

A5.2 We need to have the requisite leadership, acquisition and technical skills to be able to formulate requirements, undertake and exploit R&D. To achieve better delivery of our programmes and projects and more effective TLCM, we need to:

- Ensure better alignment of skills and behaviour to business needs;
- Deepen and strengthen our science and engineering skills base to remain an intelligent customer;
- Build closer relationships with industry and the technology supply base in general;
- Work jointly with Other Government Departments (OGDs) and industry to ensure sponsored educational outreach and training programmes are co-ordinated and effective, and aim to attract students to the science, engineering and technology subjects.

A5.3 The science and technology priorities in Section B will provide a baseline which allows us to profile our future science and technology skills requirement. Working as required with OGDs, industry, academia and others, we will then be in a position to develop plans to source, refresh and sustain these skills.

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[1] *DIS, Section B1 xvi ff.*

[2] *The Supply and Demand for Science, Technology, Engineering and Mathematics Skills in the UK Economy, Research Report RR775, 2006.*

A6 Rapid Assistance to Operations by the Science Technology Commmunity

A6.1 The UK MOD's Science and Technology (S&T) community has a long and valued history of supporting military operations. To improve the level of support, the MOD has recently introduced an initiative to provide rapid assistance to operations. This initiative will provide additional proactive assistance to current activities, complementing existing S&T involvement and providing support at the earliest possible opportunity.

A6.2 The initiative will form MOD's centralised lead for all non-nuclear S&T proactive assistance[1] across all environments and operations. It will provide this proactive assistance at two levels:

Prescient: Anticipating and supplying solutions to future issues likely to arise in current and planned operations.

Active: Capturing the issues that are extant in the operational environment but which have not been identified; or responding to those issues already identified for which either no solution has been defined or existing response mechanisms, such as off-the-shelf acquisitions, are inappropriate.

Explosive ordnance disposal using a remotely operated vehicle in Afghanistan

A6.3 The prescient assistance will be provided through think-tanks comprising appropriate Subject Matter Experts (SME) from academia, industry (both defence and civil) and the MOD (including military personnel to provide military context). By involving the wider UK S&T community the desire is to consider more innovative solutions.

A6.4 The active assistance delivery mechanism has yet to be formalised as it is a highly complex issue requiring the involvement of several key interlocutors such as PJHQ, Service Chiefs, Equipment Capability Community and the Warfare Centres. It is a first year goal for the rapid assistance initiative to determine the final delivery mechanism, building upon the wealth of experience and best practices obtained through previous UK support implementations and those of close allies.

Snatch Landrover fitted with an electronic countermeasures suite as part of an Urgent Operational Requirement

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[1] *Excluding OA and counter-terrorism already addressed by other components of the S&T organisation.*

A7 Improving Ways of Working

A7.1 In order to deliver the essential defence benefit from science and technology R&D, the UK must have an approach to management which ensures that:

- Industry has the earliest possible view of MOD's requirements;
- we have the technical skills and expertise to support TLCM;
- our systems are receptive to Technology Insertion (TI);
- we harness and exploit widely available science and technologies;
- we identify and develop science and technologies to provide military differentiators and then exploit them as widely as possible;
- we fully engage with successful and competitive UK university based researchers to harness their innovative skills and abilities;
- we take full advantage of all appropriate opportunities for collaboration.

New Generation Service Respirator

A7.2 This technology management approach requires more sharing of information between MOD and industry and much more joined-up planning, both across MOD and between MOD and industry. Increased sharing and engagement with industry is central to MOD's approach to through life technology management as articulated, for example, in the recently endorsed DPA/DLO Technology Management Strategy[1].

A7.3 There is a strong ongoing need for Towers of Excellence (ToE)[2] and similar MOD/industry technical discussion fora to develop the detailed technology roadmaps and exploitation plans required to deliver against the priorities identified in this DTS. Where, as in the case of C4ISTAR, new communities of practice[3], have evolved, by necessity, from work on this strategy, MOD will maintain this dialogue and interaction. Other opportunities for exchange of technology priorities and plans are provided by, for example, a range of Supplier Days, briefings and theme days.

Sonar 2087, an advanced sonar upgrade fitted to HMS Westminster

A7.4 The technology roadmaps and exploitation plans will:

- be informed by relevant TLCM Plans;
- take advantage of the shorter refresh cycles and exploitation opportunities offered by TLCM and TI;
- be planned as far as possible on a cross domain and/or multiple project basis;
- employ metrics such as Technology Readiness Levels (TRLs) to provide clear goals and underpin understanding and agreement of, for example, technical maturity;
- be based on sustainable enterprise models that reward investors and researchers providing routes to market for industry and provide defence benefits to MOD.

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[1] *FBG/36/08, dated 26 May 05*

[2] *Towers of Excellence, www.mod.uk/toe.*

[3] *The concept of a community of practice (often abbreviated as CoP) refers to the process of social learning that occurs when individuals who have a common interest in some subject or problem collaborate over an extended period to share ideas, find solutions, and build innovations.*

The Interactive Trauma Trainer

A7.5 Whenever the UK invests in technology development it is essential that we maximise benefit from this investment by exploiting the resulting technologies as widely as possible across different environments and systems. We must ensure that opportunities for technology insertion are available in all capability solutions.

A7.6 The DIS confirmed the MOD's commitment to pursue international research collaboration where it adds joint long-term value to Defence and may also provide science and technology solutions that will be matured for MOD application by industry. In an era when there will be increasing pressure on the Defence budget, international collaboration can help deliver value for money. It is, however, important to collaborate with the right partners to ensure that real mutual benefit is achieved.

A7.7 In this strategy we have identified those areas of science and technology where we must retain national sovereignty to ensure operational independence. This does not mean we will not engage in international research collaboration on these topics. However, whilst we are open to collaborate on them, in doing so MOD will ensure that it only engages in collaboration that does not compromise its operational independence.

A7.8 We also recognise the importance of continuing to work across government to maximise the synergy between our R&D investment and that undertaken through the DTI and the UK Research Councils for non-defence purposes. Collaborative opportunities will be assessed and included as a key element of our technology planning and roadmaps.

A8 This Document

A8.1 The DTS consists of three sections:

Section A: This introduction.

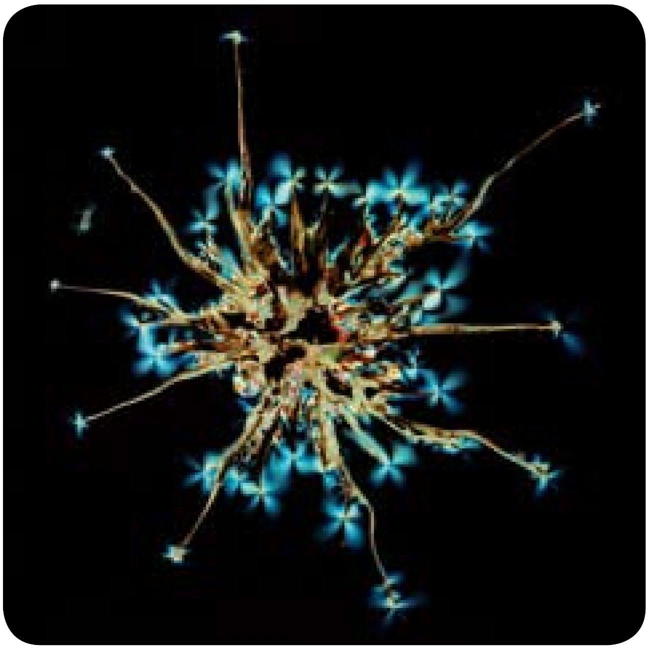
Section B: Building on the format of the DIS, this section provides greater detail of critical technologies for which research and development is likely to be required. It has the following structure:

- **B1.** Introduction (includes the criteria against which national criticality has been judged)
- **B2.** Cross-Cutting Technologies
- **B3.** C4ISTAR
- **B4.** Close Combat and Combat Support
- **B5.** CBRN
- **B6.** Counter Terrorism
- **B7.** Complex Weapons
- **B8.** General Munitions and Energetic Technologies
- **B9.** Fixed Wing and UAVs
- **B10.** Helicopters
- **B11.** Maritime
- **B12.** Emerging Technologies

The detail provided in Section B forms the basis for the planning necessary, both in MOD and in industry, to take strategic priorities forward. It identifies the areas in which we will need to invest for the future. Part B of this document sets out in detail the critical technologies for which R&D will be required to meet defence needs. If a technology is not explicitly mentioned then one should assume that it is a commodity that MOD will acquire off the shelf.

The DIS action "*…to understand the underpinning technologies that the UK must have for security and sovereignty reasons*"[1] is also encompassed within this section.

Section C: This section summarises the information presented in Section B. It sets this in context against the relevant ongoing MOD change initiatives and presents the specific actions required to take forward this strategy. The information in this section will be of most relevance to senior planners and strategists in both MOD and the defence industry, and also the university research sector.



Polymetric image of a bullet penetration of perspex

A8.2 The DTS has been jointly developed by MOD and industry, the industry contribution being provided from within the National Defence Industries Council Research and Technology (NDIC R&T) sub-group and sectoral workshops. Valuable input has also been received from members of the Defence Scientific Advisory Council (DSAC) many of whom come from the university sector.

A8.3 Each sector analysis was carried out by a study group led by the appropriate senior MOD science and technology official from within the Science Innovation Technology (SIT) organisation. The analysis drew heavily on work by existing MOD/industry fora, including the ToE[2]. Support has been provided by many other parts of MOD, particularly by the DIS implementation teams, the Dstl and the Future Business Group of the DPA.

[1] *Defence Industrial Strategy, Section C2.5*

[2] *Towers of Excellence, www.mod.uk/toe.*

A9 Affordability

A9.1 The development of the DTS is not a book balancing exercise. It clearly defines our science and technology needs to meet current and future military capability and is an essential strategic framework clearly stating where MOD and industry must invest.

A9.2 The DTS has been written as part of taking the DIS forward, including giving greater emphasis to TLCM issues. The analysis has assumed that MOD will, as now, advance technologies to an intermediate technology readiness level (TRL) for the majority of topics showing significant potential. However, driving technologies through to a mature state, particularly TRL 6 and up will require significant funding from industry.

A9.3 This DTS is affordable within planned MOD funding allocations given the right balance of funding between MOD and industry.

A9.4 Section B forms the basis for more detailed joint planning by MOD, industry and the wider UK research community, to address the next key step, which is to assess for each science and technology area the resources required to maintain priority national capabilities and ensure that our implementation plan to maintain them is jointly affordable. We will only succeed if we continue to work together.

Test firing of a refurbished SA80

A9.5 In order to focus funding as outlined in Section B, the following steps are key:

- MOD research funds for the new or growing investments will be drawn from a combination of:
  - Re-deployment of funds identified as poorly aligned in the Maximising Benefit from Defence Research study[1];
  - No longer funding research where the benefits can be obtained by buying the technology off the shelf from one of a number of potential suppliers on acceptable terms (such technologies can be regarded as 'commodities');
- Where the military benefit of the research is too low compared with that necessary to tackle new and emerging priorities.
- Industry to play a larger role in funding the more applied research, development and demonstration.

A9.6 Research through development, onto demonstration and then to exploitation in military equipment represents a spectrum of decreasing science and technology risk, but increasing cost. In order to take best advantage of advances in science and technology and the resulting sub-systems and systems that depend on S&T, it is necessary to support a relatively wide range of ideas at the early stages. To ensure research and development funds are spent wisely we will actively progress the most promising research whilst terminating those that indicate they will not deliver the required solutions.

An unmanned ground vehicle with mounted machine gun

[1] *Maximising Benefit from Defence Research – dated September 2006.*

A9.7 MOD will formulate its research programme in response to clear requirements expressed in military capability terms. Many of these requirements will be met by defining solutions based on known technologies that need further research to reduce risk to an acceptable level suitable for transition to development. For perhaps the most difficult requirements, where there is no known solution, the demand will be for new ideas based on basic research or less mature science and high levels of invention and innovation.

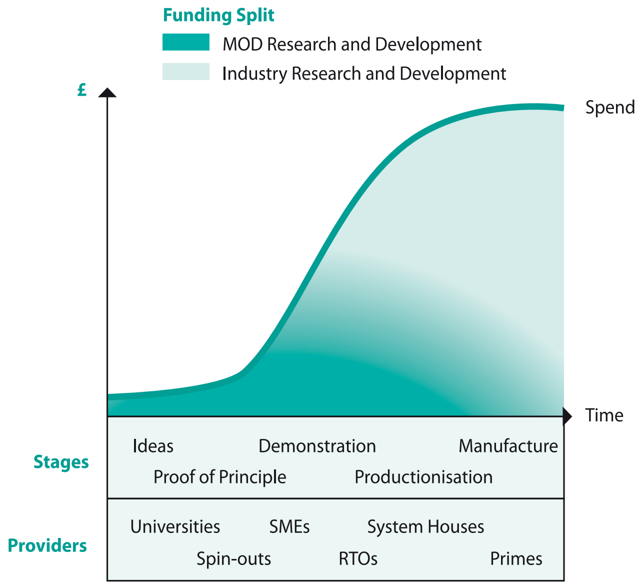


Figure 2 – Science and Technology Maturity Model

A9.8 Once beyond the initial stage of research, MOD will expect industry to play an increasing role in funding the research and development, since by this stage the level of risk will be commensurate with the potential commercial benefit to industry. At the demonstration phase, MOD anticipates industry to be making the major funding contribution.

A9.9 It is important to note that international research collaboration, which offers significant financial gearing when well planned and targeted by the collaborating partners, will be a major contributor to the successful outcomes of research and development where such collaboration is appropriate. Figure 2 illustrates the Science and Technology Maturity model discussed above.

A10 Summary

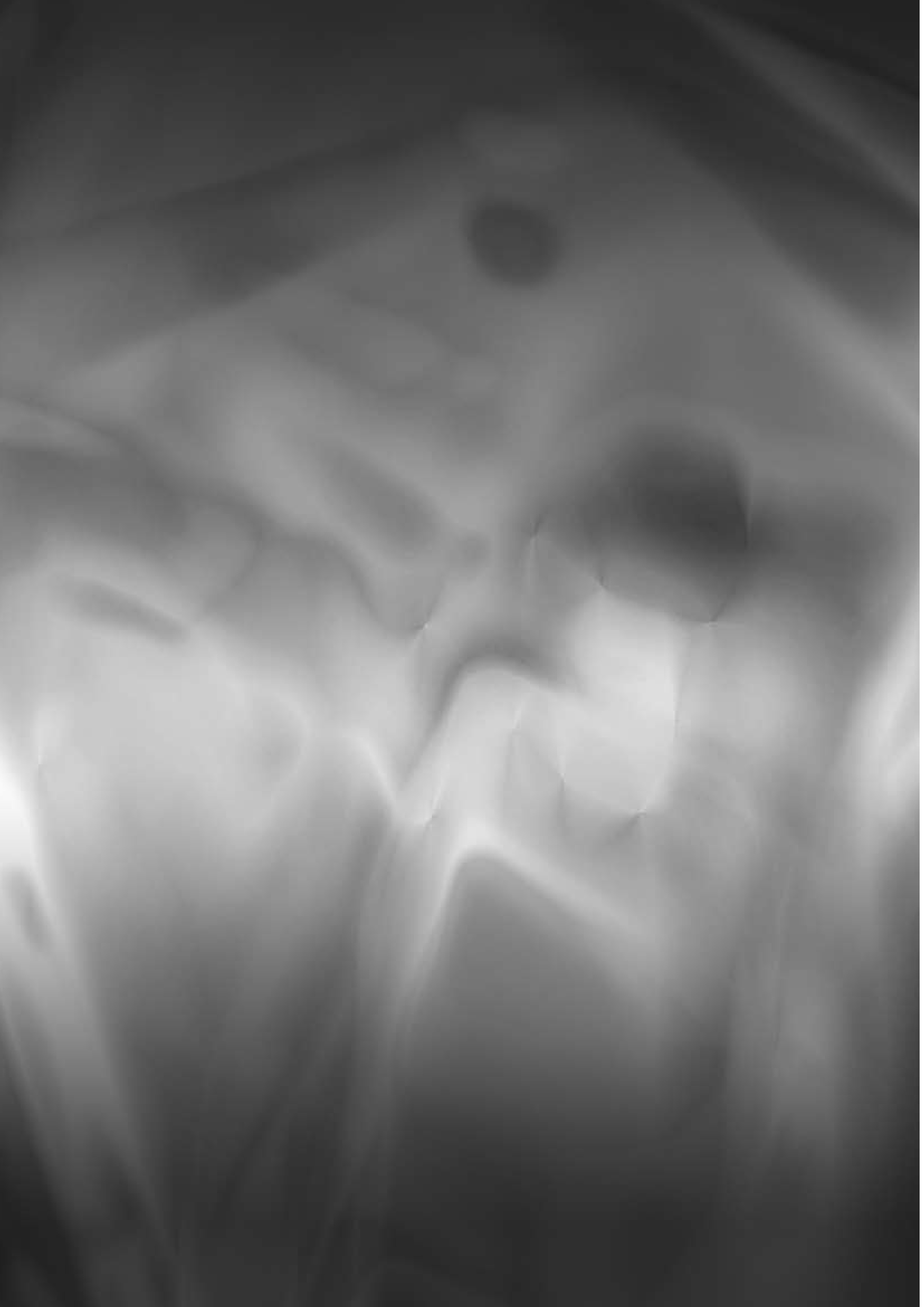
A10.1 The DTS details our agenda for change in terms of:

- Achieving our capability needs;
- Delivering on an affordable R&D programme, within planned MOD resource allocations, with the right balance of investment between MOD and industry;
- Targeting investment on those priority science and technology research and development areas MOD judge to be critical to our national interests and security;
- Continuing to review MOD priorities for the defence research and development programme;
- The need for industry to contribute to the efficacy and investment of the defence research and development programme.

A10.2 The DTS has taken us significantly further along the journey started by DIS. MOD, industry, academia and Other Government Departments (OGD's) have all contributed to this document for which we are very grateful. However, this DTS is not an end state and Section C details the way we will develop the DTS. We will ensure progress is regularly reviewed by the Chief Scientific Adviser, the Acquisition Policy Board reporting to the Minister for Defence Procurement, the NDIC R&T sub-group, and the DSAC.

Sector Analysis

section **B**



B1 Introduction

B1.1 This section sets out a detailed analysis of technology requirements to meet the defence needs stated in Defence Strategic Guidance and the Defence Industrial Strategy (DIS). The analysis considers the need for technologies and a changing approach to technology management to support Through Life Capability Management (TLCM) and reduce through life cost of ownership, as well as enhancing military capability.

B1.2 Where a specific course of action has been identified we believe that it is deliverable within planned MOD funding allocations, given the right balance between MOD and industry. The DTS clearly defines our science and technology needs to meet our current and future military capability challenges. This section forms the basis for the detailed next steps joint planning by MOD, industry and the wider research community to maintain priority national capabilities and ensure that our implementation plan to maintain them is jointly affordable.

B1.3 This section leads with the Cross-Cutting Technologies chapter which considers those technologies that deliver military advantage across multiple domains. Subsequent chapters largely reflect those in the DIS (note the Command, Control, Communication, Computers, Intelligence, Surveillance, Target, Acquisition and Reconnaissance (C4ISTAR) area is considered first). It ends with the Emerging Technologies chapter which considers those areas of emerging and disruptive technology that are of prime concern and importance to MOD.

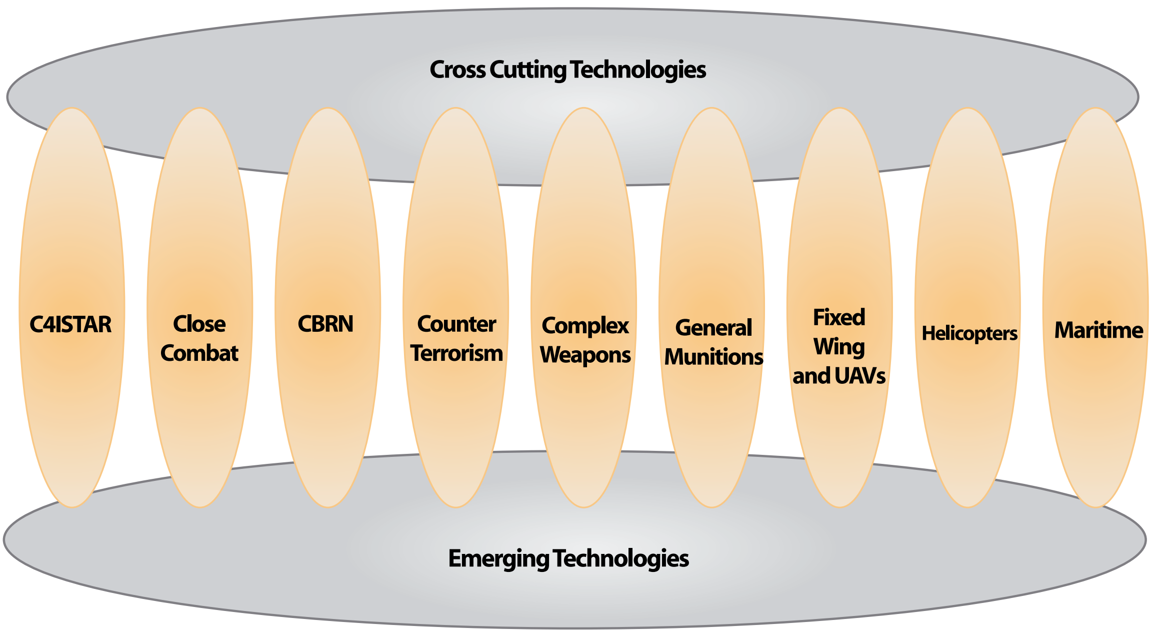


Figure 1. Section B Structure

B1.4 The MOD teams that have carried out this analysis were supported by industry representatives through the National Defence Industry Council Research and Technology (NDIC R&T) sub-group and expert advice from the Defence Scientific Advisory Council (DSAC). Several workshops were also held with attendance from a broad range of industry and Government departments. These workshops helped inform the conclusions that are presented here and identified areas of UK strength as well as gaps and trends in UK capability. The decision process is summarised in Figure 2.

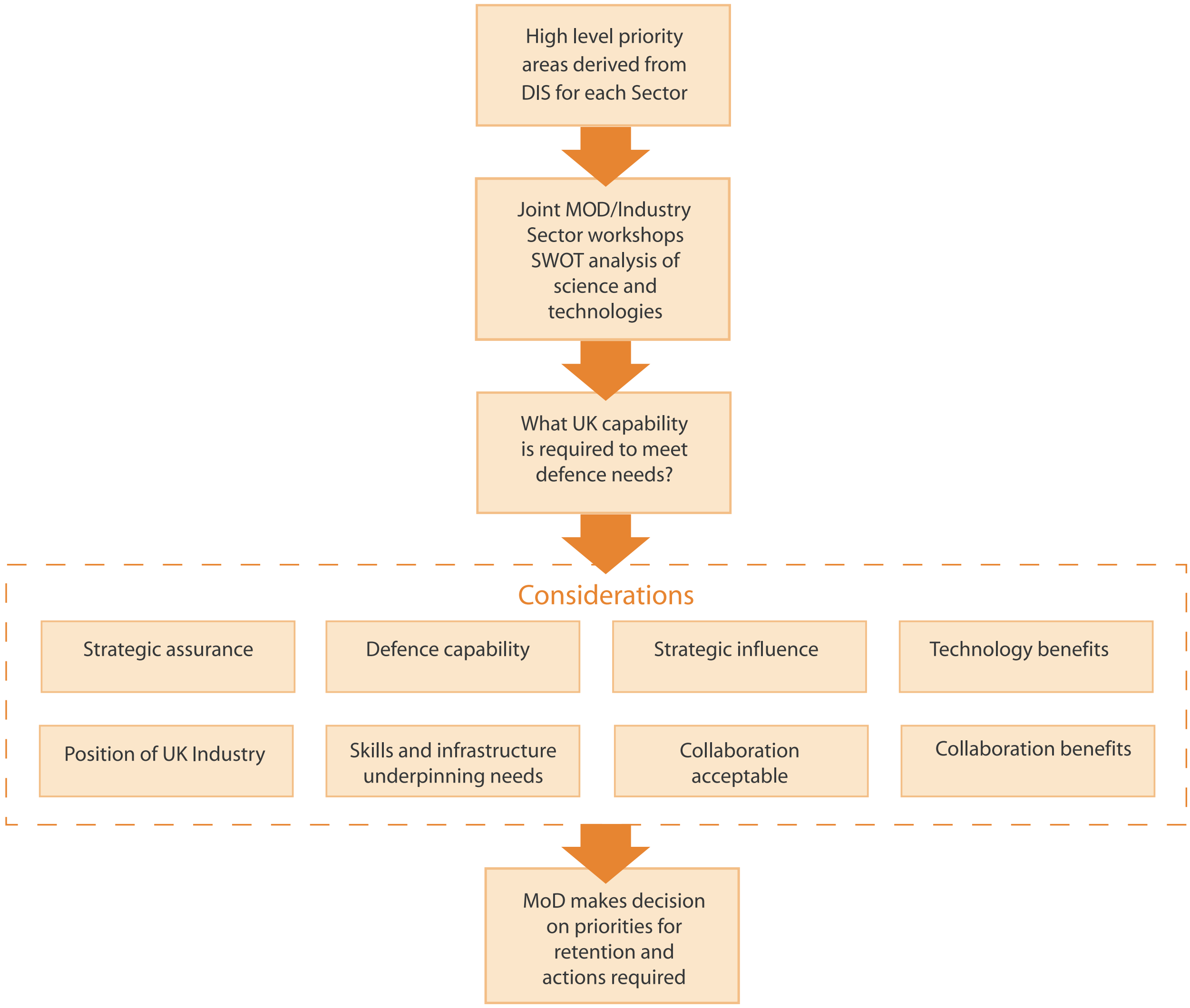


Figure 2. DTS Technologies Assessment Process

National Capability Requirements

B1.5 Throughout this analysis we have identified specific technology areas where we conclude we need to retain or develop capabilities in the UK supplier base. These are necessary to maintain the appropriate degree of sovereignty[1] over industrial skills, capacities, capabilities and technology to ensure operational independence. This is not the same thing as 'procurement independence' or a total reliance on national supply of all elements. In many, even high priority areas, we can and do rely on overseas sources, but there are critical aspects of each area where to do so would compromise this operational independence and hence our national security. These considerations also apply where specific UK capabilities give us an important strategic influence, in military, diplomatic or industrial terms; and in some cases, where retention is necessary to maintain realistic global competition – in other words, where we are not prepared to risk dependency on an overseas monopoly.

B1.6 The following criteria were used to make these judgements and were developed as part of the original DIS process:

- **Strategic assurance** – Capabilities that are to be retained in the UK as they provide those technologies necessary to safeguard the state. Such technologies could include those used within the nuclear deterrent (these are covered in a classified annex to the DTS), high-grade cryptography or those that are a key component of our counter terrorism capability.

- **Defence capability** – The development or retention of technology within the UK industrial base that is necessary for assurance of continued and consistent equipment performance or to support more general military capability. This could include those technologies of particular operational importance or aspects of more generic battlefield systems or sub-systems, where failure could present particular danger to our Armed Forces.

[1] DIS, section A1.21-22

- **Strategic influence** – Where specific UK capabilities give us important strategic influence, in military, diplomatic or industrial terms. Collaborative or complementary programmes may often be relevant here. Such programmes may be pursued to ensure value for money and affordability in complex programmes and to help enable cohesive coalition operations. The UK continues to enjoy the ability to participate actively in such programmes partly as a result of having an industrial base with a strong history of providing world class capabilities and technologies across all military environments and platforms.

- **Technology benefits** - The UK defence industrial base has in the past been a productive and innovative source of technologies and capabilities and an early adopter of technologies that have stimulated many civil applications. Defence R&D plays an important role in stimulating many technology developments in the broader civil sector and there continue to be many opportunities to pull through military technology to the civil market. Defence is often prepared to take higher R&D risks than the civil sector in new or emerging technologies because of their potential to provide a significant capability advantage. The continued investment by Government in certain defence technology areas could be necessary to help enable further opportunities in the civil sector. We recognise that this is not always a direct requirement for operational sovereignty, but it is an important consideration in ensuring that our policy is consistent with broader Government policy on promoting innovation.

In the Priority Technology tables used throughout this Section we have: identified science and technology areas that are a priority focus for our investment; defined the level of National capability requirement we need; and indicated those areas we believe collaboration will be most beneficial for meeting those needs.

International Research Collaboration

Overview

The DIS[2] reaffirmed that MOD will pursue international research collaboration where it adds long-term value to Defence. For the UK, the value of such collaboration comes principally from increasing our science and technology knowledge base.

A recent study sponsored by the MOD's Chief Scientific Adviser[3] identified that, whilst the MOD's research programme is satisfactorily aligned with our strategic needs, still more focus is required on the UK's defence priorities. We therefore need to ensure that the benefits of international research cooperation are not outweighed by a loss of focus on UK needs; just aiming to spend more cooperatively would be a false target. Furthermore, we must work more effectively with our collaborative partners to ensure we engage in programmes of true mutual benefit. Partners will not collaborate unless they see clear benefits for themselves. On a bilateral basis, our biggest collaborative partners are expected to remain the US and European nations. Multilaterally, we will continue to fully support key fora where they deliver substantive benefit to UK Defence.

Cooperation with the United States

The US remains our key partner for research and technology collaboration. Just as UK and US armed forces face many common operational challenges, so our research programmes address common technology issues. The UK's defence planning assumptions for large scale operations require the UK Armed Forces to be interoperable with US command and control structures, match US operational tempo and provide those capabilities that deliver the greatest impact when operating alongside the US[4]. An effective UK-US technology partnership is an essential factor in achieving these aims.

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[2] *Defence Industrial Strategy, Section A5.29ff*
[3] *Maximising Benefit from Defence Research dated September 2006*
[4] *Defence Industrial Strategy Section A2.3*

Currently, UK-US cooperation covers a wide spectrum of defence technologies, delivering substantial mutual benefit. Both UK and US military systems benefit from unique, world-leading technologies that have been developed or shared through our collaborations; the pooling and exchange of research work delivers hundreds of millions of pounds / dollars of mutual benefit to both countries. We will continue to support this key relationship and to foster new UK-US collaborations in areas of mutual benefit. However, we also need to ensure that we maintain an efficient collaborative process that allows appropriate, equitable technology sharing.

Cooperation within Europe

The DIS identified that our objectives in European collaborative research will increasingly focus on joint industrial programmes to develop defence technology[5], with European research and technology cooperation currently bringing tens of millions of pounds of benefit to UK defence each year. Over two-thirds of this benefit comes from bilateral activities, with France being our biggest partner. At the Franco-British bilateral security and defence summit[5] in June 2006 the two countries emphasised that we would like cooperation between our two countries to help us maintain on our territory the technologies that are essential for sovereignty, and that we intend to encourage a more systematic approach to cooperative projects.

Some 93% of European defence research and technology spending is undertaken by only six member states[6], namely France, Germany, Italy, Spain, Sweden and the UK; with France and the UK alone accounting for nearly 70% of the total spend[7]. An October 2005 report to the defence research directors of these nations found little evidence of fragmentation or duplication in their government funded defence research and technology. Moreover, only 7% of defence technologies considered (18 out of 261) were common priorities for all six nations; much stronger commonality being evident bilaterally (74%) and trilaterally (45%).

It is our assessment that within Europe co-operation is best achieved bilaterally or within small groups of nations, rather than by broad multilateral programmes or by strategic coordination at a pan-European level. The likely loss of focus on national technology priorities makes the latter approach potentially counterproductive. The European Defence Agency is a potentially valuable enabler for facilitating and supporting cooperation between these smaller groups of European partners; for example the recent Franco-British initiative on lightweight radar[8].

Within Europe, the UK will increasingly look towards focussed research and technology cooperation with key defence partners as the best way to improve national, NATO and EU defence capabilities. A good example of this is the intention of the French and British defence ministries to partner with industry in setting up an Innovation and Technology Partnership to identify, assess and develop future guided weapons technologies.

Broader collaboration

Cooperation with other valued partners can bring huge benefits to the nations involved. For example, The Technical Cooperation Program between Australia, Canada, New Zealand, the UK and the US enables the exchange of some £250 million of research information per year. We will therefore continue to collaborate with such partners in areas of mutual military and technological benefit. Another good example is NATO's Research & Technology Organisation, which is a mature and proven organisation that brings together Europe and North America.

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[5] *http://www.number-10.gov.uk/output/Page9590.asp*
[6] *http:/www.eda.europa.eu/facts/Defence%20R&T%20Spend.htm*
[7] *http://www.eda.europa.eu/facts/National%20Defence20R&T%20Data.htm*
[8] *http://www.number-10.gov.uk/output/Page9590.asp*

B2 Cross-Cutting Technologies

Introduction

B2.1 Cross-cutting technologies are those which can deliver military advantage across multiple domains. Investment in these technologies can achieve high gearing and widespread military effect through re-use in many areas. Particular UK technical strengths with widespread battle winning applications are: thermal imaging, radar, signal processing, communications EW, human performance and training.

B2.2 Based on our analysis of Sector needs, the topics identified below are the important cross-cutting technologies:

- Sensors and countermeasures;
- Information exploitation;
- The human as part of the system;
- Platforms and structures;
- The physical environment;
- Technologies to enable Through Life Capability Management (TLCM).

B2.3 In addition, the C4ISTAR chapter of this strategy covers technologies that are cross-cutting and have impact across all sectors but we have chosen to address them under one heading in a separate chapter.

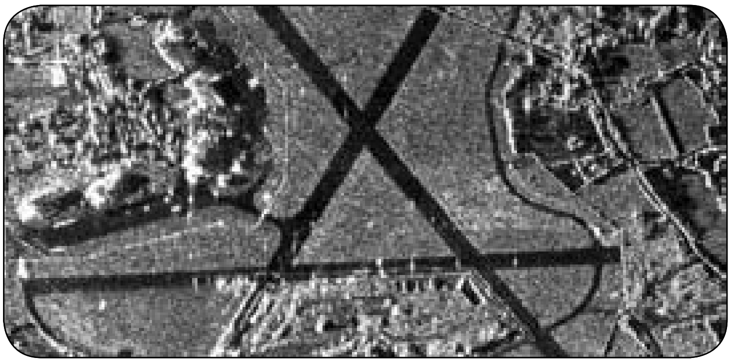
Radar Operator

Sensors and Electronic Warfare

Introduction

B2.4 Modern military capability is underpinned by sensor and communication systems that exploit the Electromagnetic (EM) spectrum. The UK Defence Doctrine recognises the EM spectrum as an operational environment in its own right. This reliance on the EM spectrum will increase significantly as Network Enabled Capability (NEC) is progressively realised. Hence sensor and countermeasure systems will continue to be of great importance to UK defence.

B2.5 Although individual sensor and countermeasure technologies are discussed, it is important to stress the increasing importance of systems that combine information from different parts of the spectrum and different sensing modalities, together with 'near sensor' digitisation and signal processing. The data fusion techniques addressed in the C4ISTAR chapter will then be exploited to provide flexible adaptable and integrated sensor systems.



Synthetic Aperture Radar Image of an airfield

Table 1. Summary of Priority Technologies for Sensors

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Radar	Solid-state transmit/receive modules and e-scan array manufacture Instantaneous wideband e-scan steering Processing for high resolution and imaging radar Lightweight multifunction Radio Frequency (RF) apertures Low phase noise signal generation High dynamic range receivers Rapidly tuneable low loss RF filters Multifunction radar architectures, radar resource management, control, operation and data processing in a networked environment including all relevant signal and data processing techniques Low observable antennas/apertures	National capability to research, design, manufacture and integrate technologies into radar systems	Compact RF payloads for tactical surveillance
Electro Optic (EO) Sensors	High Performance IR detectors Detectors for 'eye-safe' active imaging systems New research approaches to exploit EO amplitude, spectral, polarisation, phase and time profile	Certain UK industrial capability to design, manufacture and integrate into systems	
EO Protection Measures	Sensor and eye protection against dazzle and damage laser attack	National capability to design and integrate into sensor systems	
EO Counter-measures	Compact rugged sources with military specific spectral and power outputs Beam steering systems for pointing and tracking Adaptive systems to mitigate atmospheric effects	UK access and ability to integrate into systems	Beam control technologies
Other Sensor Technologies	Novel approaches to sensing and combining sensors		National research programme using collaboration
Signal and Data Processing	Non-linear, non-Gaussian, non-stationary signal processing Cognitive signal processing Blind/semi-blind signal processing Power efficient techniques Advanced detection, tracking and recognition algorithms to maximise automation Broadband signal separation Auto calibration	Ability to research, design, evaluate and integrate advanced signal and data processing algorithms and apply them in systems	
Materials and Devices	Semiconductor devices for RF transmit/receive modules	Secure access to device foundry by UK companies	Design and fabrication

Radar

B2.6 Radar is a vital component of many current and future land, sea, air and space defence systems including:

Tornado F3/GR4	Typhoon	Joint Combat Aircraft
Nimrod MR2/MRA4	Brimstone Anti-tank missile	Watchkeeper UAV
Airborne Stand Off Radar	Lynx helicopter	Future Rotorcraft
Merlin	T42/T45 Destroyer	T23 Frigate
Future Aircraft Carrier	Counter Battery Radar	Maritime Airborne Surveillance and Control
Man-portable Surveillance and Target Acquisition Radar	Meteor - Beyond Visual Range Air to Air Missile	Sea King Mk7/Airborne Early Warning
Advanced Medium Range Air-to-Air Missile	Sentry Airborne Early Warning and Control aircraft	

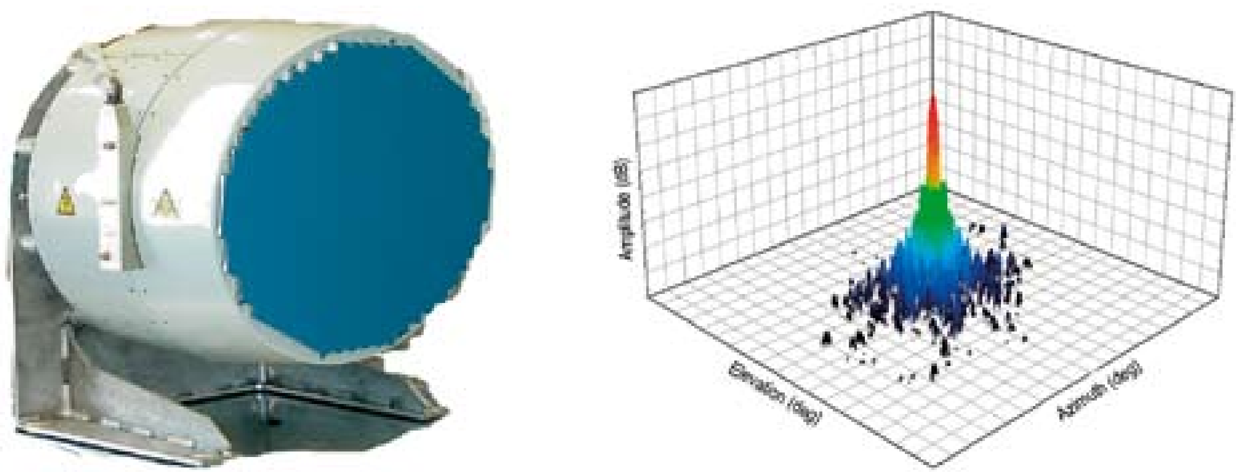
B2.7 Such extensive dependence on radar, both now and for the foreseeable future, coupled with its anticipated continued pre-eminence in long range, all weather sensing, establishes the need for a high level of UK national capability in this technology. This requires the retention in the UK supplier base of the ability to specify, design, integrate, maintain, modify and assure complete radar systems. The table lays out many of the technologies that need to be retained in the UK. But others are:

Multifunction Electronically Scanned Adaptive Radar. © BAE Systems

- Critical RF component technologies, including assured access to GaAs, GaN, InP and SiGe device technologies.
- Electronic attack and protection against electronic attack.
- Target detection, recognition, identification and tracking algorithms, including all relevant signal processing techniques.
- Power efficient processing techniques.

B2.8 The scope of radar applications within defence is broad, but can be typified by three generic types of system:

- Airborne combat radar.
- Airborne surveillance radar.
- Surface radar.



Airborne multimode radar with broadside transmit beam pattern

B2.9 Working with industry and academia through the Radar Tower of Excellence, which draws its membership from all levels in the supply chain, an outline strategy for future radar technology has been developed. This strategy is based on demonstration programmes for the three generic types of radar system, supported by a suite of underpinning technologies.

B2.10 The three radar demonstrator programmes will:

- Use an open systems approach
- De-risk radar technology to a level for UK industry to make attractive submissions to competed procurement programmes.
- Provide a vital step towards exploitation of the research programmes.
- Provide the opportunity for the supplier base to align their research and development activities with the MOD in these areas.

B2.11 The diagram below illustrates the development of the rationale for the radar demonstrator programmes.

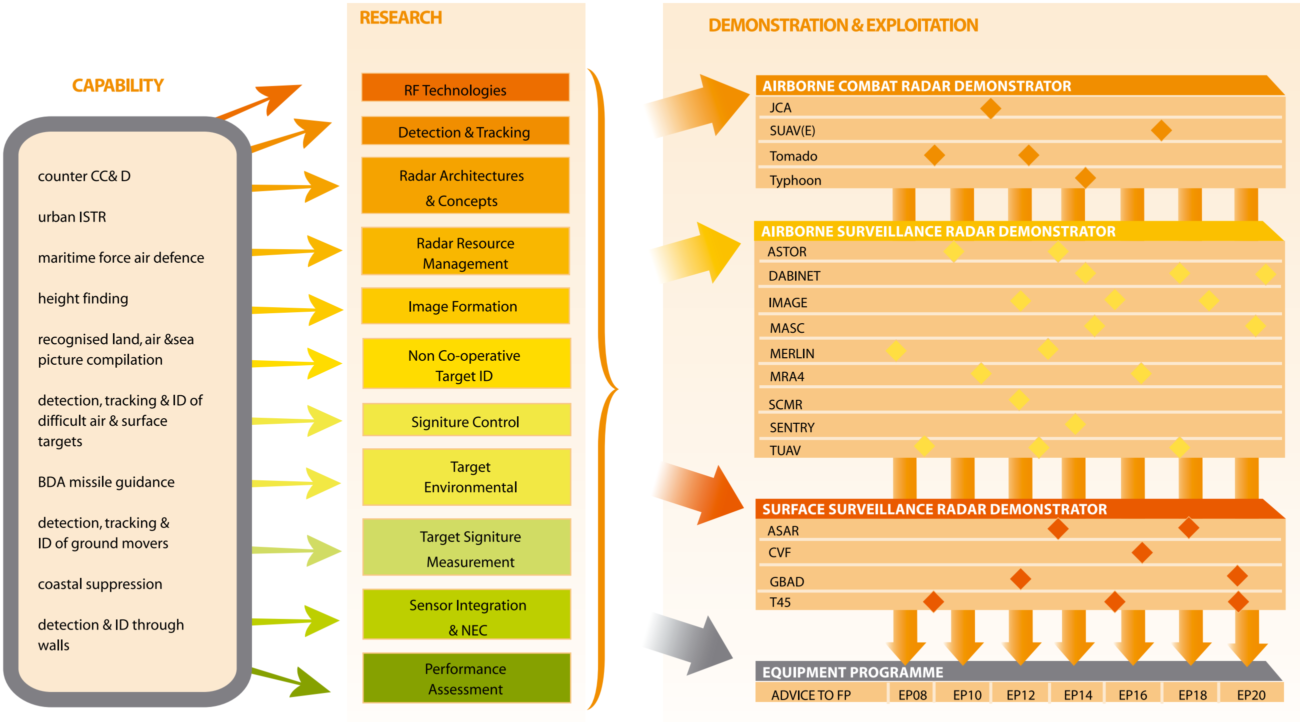


Figure 1. Radar demonstrator programmes

B2.12 MOD is working with industry and academia to convert the outline strategy developed through the Radar Tower of Excellence into a detailed plan with a clear commercial procurement strategy. This will ensure that technology developments from all sources can be harnessed and exploited through industry managed radar demonstrator facilities.

B2.13 MOD is working with other European nations through the European Defence Agency to identify collaboration opportunities for compact RF payloads for tactical surveillance.

Electro-Optic Technologies

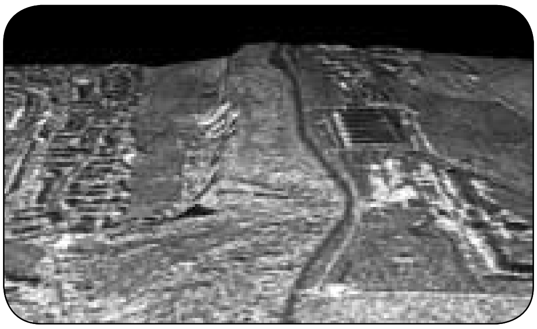
B2.14 Advanced electro-optic (EO) technologies cut across all DIS sectors. EO technologies underpin a wide range of key UK military capabilities such as the provision of high resolution surveillance; target detection, identification and aim point selection; day and night war fighting; autonomous control and manoeuvre; range-finding; sensor protection; missile guidance; threat detection; signature control; and active countermeasures.

B2.15 For the foreseeable future and despite limitations in bad weather, EO sensors will continue to play a large role in defence systems. Since UK rules of engagement are likely to remain more stringent than those of our opponents it is essential that the UK maintains a technical lead in EO technologies.

EO Sensors

B2.16 Much EO imaging technology is now widely available and is often relatively inexpensive. Therefore it is essential that the UK harnesses these commodity technologies to provide the required improvements in situational awareness. Substantial R&D investment by MOD is not required in this field, but MOD will continue to explore novel approaches that are not being developed in the civil sector.

B2.17 In other EO imaging applications advanced technology can provide military differentiation by enabling target identification at longer ranges than our opponents. Therefore the ability to buy, maintain, upgrade and adapt high performance EO target identification imaging systems in the UK is a high priority. Unlike some of the commodity EO technologies referred to above, their availability is strongly dependent on defence investment. These imaging systems may employ discrimination exploiting polarimetric, temporal, multi-band and/or hyperspectral signatures.



Interferometric Synthetic Aperture Radar image of Dstl's Portsdown West site

B2.18 There are a number of areas of EO technology where sustained research investment has given the UK a very strong position. Two important examples are very high performance staring array Infra-Red (IR) detectors, and detectors for 'eye-safe' active EO imaging systems. Emphasis must now be placed on exploiting these through technology and system providers to maintain the strong position the UK has long held in IR imaging systems. MOD will now work with industry through the EO Tower of Excellence to refocus investment in EO components towards exploitation of existing knowledge and expertise for production and application of high performance IR staring arrays and active imaging detectors.

B2.19 Given the relative maturity of EO components and conventional imaging systems it seems likely that large improvements in future performance, as required to address detection and identification of the many targets, in all environments that still present a major challenge to defence, are most likely to result from exploiting EO technology in more novel ways. For example, the exploitation of EO in defence applications has yet to benefit fully from similar algorithmic developments to those seen in radar (e.g. exploiting phase difference techniques). MOD will re-position its EO research activity to maximise innovation and address new sensor concepts that explore radically new ways of improving EO sensor systems and their cost effectiveness.

EO Protection Measures

B2.20 Laser systems will become commonplace in the future battlefield, both for their role in sensing and also for sensor-defeat. In an EO-rich battlefield, the need for adequate sensor protection will become paramount as potential adversaries acquire COTS/MOTS laser systems.

B2.21 Electro-optic protection measures (EOPM) to protect eyes and sensors from dazzle and damaging laser attack is an important strategic technology. EOPM, which includes protective coatings and filters, is best considered as an integral part of EO system design. Adding EOPM at a later stage of development is very costly and may not be possible without significantly prejudicing the performance of the sensor.

B2.22 The specification of EOPM, which requires a detailed knowledge of the threat, identifies a sensor vulnerability, which will be sensitive and must be protected. The UK must retain a capability to design, assess and test EOPM in order to specify, assess, evaluate and test protected sensors.

B2.23 **The UK has an excellent research capability in EOPM. This research will be maintained and linked more closely with sensor system suppliers through demonstrator programmes carefully targeted at key sensors and technologies. This will advance the TRL of EOPM, de-risking potential applications across a wide sensor base and hence increasing affordability.**

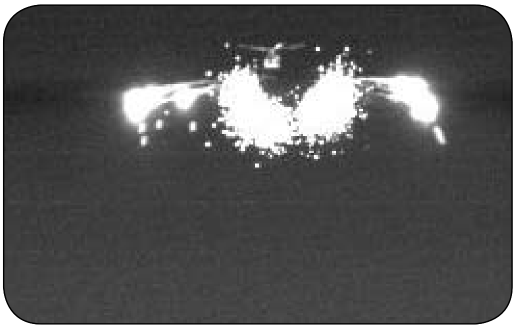
Protection against laser dazzle

EO Countermeasures

B2.24 Electro-optic counter measures (EOCM) are becoming increasingly important, in particular for defeat of sensors used to guide weapons systems. Development and upgrade of EOCM systems requires detailed knowledge of threats and since they are often an important aspect of survivability the ability to design, sustain and rapidly adapt EOCM systems to meet emerging threats must be regarded as a high priority national capability. In addition to the threat-related control software, the key elements of EOCM systems are sources of appropriate wavelengths and powers (usually lasers), power distribution and beam control technologies.

B2.25 Many laser products can be regarded as commodity items but the compact rugged systems that are essential for most military applications are defence specific and the UK has good industrial capability in this area. EOCM applications often demand specific spectral characteristics, and there may be no large civil market driver for this type of laser system. An example is mid-IR laser systems for in-band defeat of heat seeking missiles where the technology only has military applications. Broad-spectrum 'white-light' lasers have great potential for EOCM and also in active imaging systems and remote detection of biological or chemical agents. **MOD will target its investment in laser sources against important military specific technologies and seek collaborative gearing where possible.**

B2.26 It will be important to retain the ability to specify, design and make wide-band beam steering and beam quality correction systems, effective at militarily significant powers and bandwidths. Enabling technologies are likely to include adaptive optics, possibly MEMS based, phase-control and combination of multi-beams. There is little commercial pressure to develop this technology as mechanical beam steering is sufficient for most civil applications. **MOD will invest in beam control technologies for EO countermeasures taking benefit from any international collaboration opportunities.**



Infra-red image of Chinook releasing flares

Other Sensor technologies

B2.27 In addition to the RF and EO sensors, there are other regions of the electromagnetic spectrum, or other sensor modalities such as those exploiting acoustics or gravitational fields, that may be exploited to detect and identify difficult targets.

B2.28 Emerging asymmetric threats and the problems of finding and tracking hostile activity in busy urban environments create a new and urgent need to devise new sensing solutions. Particular needs include the detection and characterisation of installations and activities in buildings or underground using remote sensing techniques, and identifying and tracking the source of potentially dangerous activity or intent in areas of otherwise normal activity.

B2.29 For other important threats there are techniques for detecting and locating the offending items (such as the source of mortar and sniper fire; mines; biological, chemical and explosive substances) but there is a need to improve the speed, accuracy and reliability with which these threats can be handled, particularly from stand-off locations.

B2.30 Integrated logistics requires sensing solutions to enable asset tracking and status monitoring of platforms and equipment. Many of the solutions in this area, such as RF Identification tagging, will be driven by civil markets but defence applications have some specific needs. These include the ability to be covert in operational areas and to provide seamless tracking as stores are transitioned between very different modes of transport in harsh environments.

B2.31 **MOD will continue to invest in novel sensing technologies. We will explore further the benefits of working with groups involved in differing areas of novel sensing research in academic, government and industrial laboratories as a stimulus for innovation and exploitation.**

Electronic Warfare (EW)

B2.32 Recent operational experience has re-confirmed the vital and integral role of EW in military operations across the spectrum of conflict from terrorism, through peace support to high intensity conflict.

B2.33 EW is subdivided into the three main activities:

- Electronic Surveillance (ES).
- Electronic Attack (EA).
- Electronic Defence (ED).

Thermal imaging

B2.34 Electronic surveillance provides strategic intelligence by intercepting various transmissions. It also provides tactical situational awareness as a key enabler to survivability by detection, identification and location of threats. Analysis of data collected by ES results in a detailed understanding of threat systems and is essential to the success of Electronic Defence and Electronic Attack. EA denies hostile use of the EM spectrum by targeted disruption of communications and sensor operation, such as by high power jamming. ED covers both the protection of platforms through tactics and countermeasures and the hardening of our own systems against hostile EA.

Table 2. Summary of Priority Technologies for Electronic Warfare

Function	Priority Technologies	National Capability Requirement
Maritime	ES for submarines and future surface combatants. Maritime Integrated DAS Improved defeat of both RF and EO/IR threats to surface warships. Radar ES in littoral operations Threat warning systems in the littoral. DEW including NLW for effects based options, especially in the littoral	Deep technical understanding of threats Assured capability to rapidly develop and fit improvements to EW systems. National capability to re-program EW systems. Security of supply of countermeasure (EA & ED) technology and techniques Assured capability to maintain operational effectiveness of ES. Deep systems engineering expertise to specify equipment and architectures and ensure test and evaluation. Rapid response to emerging threats
Close Combat	Affordable Defensive Aids Systems (DAS) Multifunction sensors and effectors. Threat warning systems EOCM	Deep technical understanding of threats Assured capability to rapidly develop and fit improvements to EW systems. National capability to re-program EW systems. Security of supply of countermeasure (EA & ED) technology and techniques Assured capability to maintain operational effectiveness of ES. Deep systems engineering expertise to specify equipment and architectures and ensure test and evaluation. Rapid response to emerging threats
Air (Fixed Wing, Rotary and UAVs)	Threat warning systems including Hostile Fire Indication Advanced IR Countermeasures Advanced RF Countermeasures Integrated EW management DAS EO Countermeasures Small and affordable sub-systems Multifunction apertures. Compact integrated payloads DEW technologies and systems	Deep technical understanding of threats Assured capability to rapidly develop and fit improvements to EW systems. National capability to re-program EW systems. Security of supply of countermeasure (EA & ED) technology and techniques Assured capability to maintain operational effectiveness of ES. Deep systems engineering expertise to specify equipment and architectures and ensure test and evaluation. Rapid response to emerging threats
Complex Weapons	Directed Energy payloads (EO and RF) Navigation Warfare Programme (NAVWAR) ED to protect seekers, fuses and datalinks	Deep understanding of technology and systems to specify equipment. Assured capability to maintain operational effectiveness.
C4ISTAR	Techniques and technology for ES and EA Geolocation of threats and systems ED to protect communications and networks	Deep understanding of technology and systems to specify equipment and architectures. National capability to re-program EW systems Assured capability to maintain operational effectiveness
Counter Terrorism	EW, particularly ES Less Lethal Weapons	Deep understanding of threats Deep understanding of technology and systems to specify equipment National capability to optimise system performance.

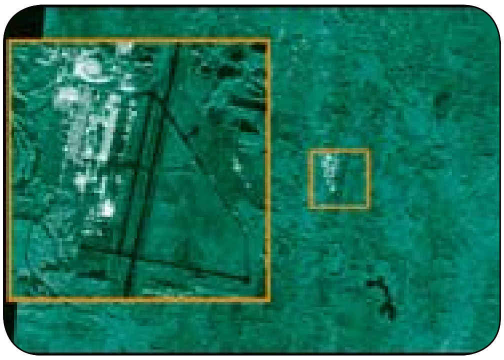
B2.35 EW is realised through the use of sensors/effectors primarily operating in the RF and EO parts of the EM spectrum. Many of the technologies used in EW are therefore included in, or are closely associated with, the sensor technologies described above.

B2.36 The principles of our EW technology strategy are:

- Appropriate sovereignty to be able to use UK EW capability without constraints.
- Assurance that EW equipment will operate as required, at all times.
- Maintenance of indigenous key, time-critical industrial skills and capabilities to support Urgent Operational Requirements (UORs) in response to fast-changing operations.
- Indigenous expertise and ownership of system architectures that support Through Life Capability Management (TLCM).
- Intelligent customer status coupled with the need to ensure intelligent user status for current and future capability.

B2.37 Detection, identification and geolocation of threats are critical to an optimised military response and EW sensors provide unique capability against key strategic and tactical threats. Enhanced signal processing will increase the utility of this capability as will better geolocation and synchronisation technologies.

B2.38 UK capabilities in modelling and simulation and Hardware in the Loop (HWIL) are, in some areas, very good. We have a world-class capability to test IR countermeasures in flight, using fixed ground threats, but need to improve our capability for live fire, which is increasingly being shown to be critical to the design of warners and countermeasures.



ASTOR imagery of an airfield

B2.39 The UK currently has an excellent indigenous technical capability in EW with strength at prime contractor and technology provider levels together with a very capable and broad SME base and some strong research in universities. A good Defence community exists between these players and this is focused around the EW Tower of Excellence.

B2.40 To develop specific capabilities to high technology readiness levels (TRL) and also to develop and sustain the required national EW expertise, a small number of targeted demonstrator programmes will be chosen to reflect areas of major potential operational importance. The EW Tower of Excellence is ideally positioned to play an active role in a debate on the prioritisation of demonstrator programmes, but potential programme areas include:

- EO/IR countermeasures, based on compact laser systems together with advanced flare decoys, to defeat future EO/IR threats.
- Technology, including processing, for advanced communications Electronic Surveillance (ES) in complex environments. Such systems are crucial to situational awareness in all operational scenarios including the assessment of threats to own networks.
- Advanced radar ES applicable to complex, modern transmitters in complex scenarios.
- RF Multi-Function Apertures (MFA) built on current electronic scan array radars offer significant potential for advanced, high power RF Electronic Attack.
- Affordable systems, both ES and EA, for future UAV payloads will be key to the development of networked EW capability.
- Threat detection of EO/IR threats is a key requirement in all service environments. EO/IR MFA offer the potential for novel techniques for fusion of information.
- Directed Energy Weapons offer new and different options. There is a need to pull-through the technology to a higher TRL level.

B2.41 **MOD will work with suppliers through the Tower of Excellence to refine future investment and exploitation plans, explicitly identifying the opportunities that are best demonstrated by targeted programmes and then realised across different platforms and sectors by the adoption of a Through Life Capability Management approach to EW systems.**

Signal and Data Processing

B2.42 Military sensor systems must operate in real-time, often using compact, low power-consumption processors. Signal processing techniques provide the first step in the overall information processing chain and signal processing performance is therefore critical to the whole chain.

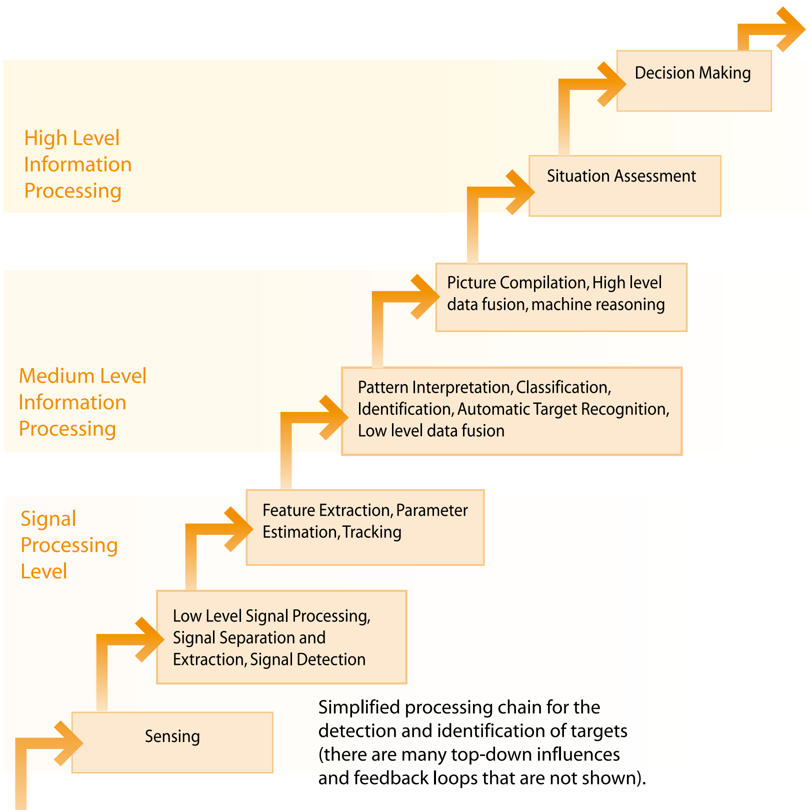
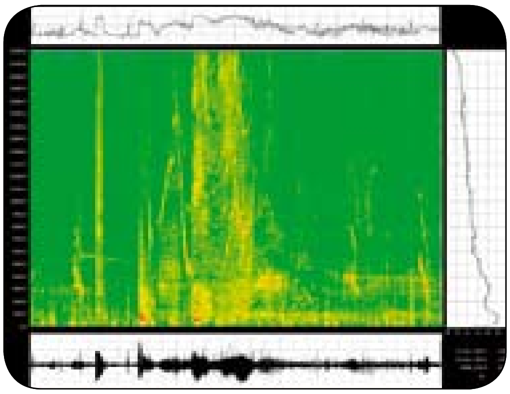


Figure 2. Processing chain for the detection and identification of targets

B2.43 The UK has a long and strong record in developing generic signal processing techniques, and then applying these techniques to improve the performance of military systems. Developments in generic signal processing techniques made during the 1980s and 1990s underpin the dramatic advances in performance of current sensing, surveillance and communications systems. The subject is relatively mature, but the limits of its scope have not been reached and signal processing continues to provide a challenge. Digital Signal Processing has a key role in improving system performance when cost is a crucial constraint and innovations in signal processing technology will be at the heart of many further innovations in military systems.



ASTOR imagery of an airfield

B2.44 In modern and future networked environments, the signal and information processing must operate across, and integrate signals from, the networked sensor elements. This is necessary to exploit the potential of networked sensors to detect currently undetectable targets, and to achieve the required levels of discrimination between real targets. The time is ripe for merging the disparate aspects of data adaptive signal processing and information processing to achieve a form of intelligent signal processing (ISP) where the processing algorithms adapt.

B2.45 There are two reasons why the UK needs to maintain the current strong position in signal processing:

- To ensure that the UK develops new (generic) ideas/algorithms, and provides signal processing expertise.
- To invest in the further engineering steps required to tailor generic forms of algorithm into robust real-time application-specific algorithms that can be implemented in real military equipments. This is much more resource-intensive, and requires additional specialist expertise, such as a representative test environment.

B2.46 There is a very strong case for approaching signal processing on a national basis to develop the required skills and experience, provide access to application specific data sets and testbeds, and enable the rapid and cost effective pull-through of generic techniques into applications. The principal resource which is required in order to lead innovation in signal processing is people who have the high level of specialist knowledge required to make advances in the area.

B2.47 **MOD will work with the Research Councils and Universities to ensure that emphasis is placed on post-graduate education and training in signal processing, ensuring that academia is supported through the provision of challenging problems and where appropriate suitable data sets. The development and application of signal processing techniques will be identified as a very high priority within the MOD research programme. We will establish a Defence community of practice, which embraces academia, RTOs, manufacturing industry and the Defence Technology Centres to establish the courses, training environments, test beds and datasets necessary to support a cutting edge signal processing capability in the UK.**

Electronic Materials and Devices

B2.48 While many of the components and circuits needed for sensor and countermeasure systems will be available from sources focused on civil markets, there is a need for the UK to ensure continued access to some critical advanced components and circuits. The most important of these are solid-state RF transmit/receive modules based on advanced semiconducting materials. It is essential that the UK maintains on-shore access to these technologies.

B2.49 The current generation of high power microwave devices are based on Gallium Arsenide (GaAs) and in the UK Filtronic is the only major provider of GaAs technology on a foundry basis. While this provides an excellent capability for defence in the UK, the existence of the foundry depends on the existence of large civil markets for its products.

B2.50 The next generation of power devices, critical for future EW and RF systems is likely to be fabricated from the material Gallium Nitride (GaN). The UK has a limited research programme on GaN technology that is part of a multi-national European research programme. However, these activities will not in themselves ensure future access to GaN component technology. MOD will work with defence manufacturers and European Procurement Agencies to identify what UK investment is required to ensure that UK companies will be able to access GaN technology within Europe.

B2.51 The development of GaN can be considered as part of an ongoing systematic development of wide band-gap materials, including diamond. This is likely to lead to a range of new components. The most dramatic impact will probably result from the introduction of lighting by white LEDs, with major savings from increased efficiency and greater reliability. This application will be driven hard by civil investment.

B2.52 The ability to package electronics correctly, particularly for high power applications is also very important and current technology cannot meet the full requirements of defence. Relevant areas are:

- High Power Electronics Packaging.
- High-temperature packaging.
- High Speed, High Density Packaging.
- High Frequency Packaging for SiGe, GaN, SiC, and diamond devices.
- Free Space and Guided Wave Optical Packaging.
- Microwave photonics and optical processing technologies.

B2.53 This very wide range of technologies makes a comprehensive defence-specific programme on electronics packaging unaffordable. **MOD will seek to target its investment against specific high value applications exploiting as far as possible technology advances arising from civil investment (also see Electronics Hardware).**

Technology to Exploit Information

B2.54 Information has always been an important enabler for military command and control. The introduction of Network Enabled Capability (NEC) will make a large range and volume of information available to much wider military audiences in near-real time. However, to enable this information to be exploited effectively is a much more difficult task than simply making it available to the user.

Secure networking

B2.55 The large civil investment in information and communications technology (ICT) will satisfy a large part of the defence information and communications infrastructure requirement, but civil technology will not be able to provide the complete capability required by the Armed Forces. There are a number of underlying ICT technology issues, which have broad application across the sectors that are summarised below.

Table 3. Summary of Priority Technologies for Information Exploitation

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Secure & Robust Communications	Algorithms to support ad-hoc networking of military systems Security and dependability of ad-hoc sensor and communication networks Exploitation of frequency and spatial diversity to achieve increased bandwidth Optical communications technologies	National capability in algorithms for Ad-hoc networking	Develop and maintain security architectures for ad-hoc networks Cognitive radio systems Free space optical communication technologies
Information Management	Scalable algorithms Inference of metadata Architectures and frameworks that support secure interoperability Ontologies and translation between ontologies	Architectures Ontologies	All aspects for interoperability

B2.56 Many defence communications systems have to be deployed rapidly, have to work in difficult environments and must provide a high level of information assurance, both short and long term. The military networks to support tactical forces are particularly challenging requirement since they must be mobile, robust to attack and resilient to failure. Furthermore, as data rather than voice comes to dominate network traffic and IP networks become ubiquitous, new challenges will emerge for traffic management and security.

B2.57 Ad hoc networks, which are networks with no central control and no dependence upon fixed infrastructure, are a natural fit for such tactical applications. Unlike civil concepts, military ad hoc networks will need to scale to larger numbers of devices and information may need to pass over numerous wireless communication hops before reaching the backbone communications infrastructure. Achieving the necessary scaling to meet military requirements, whilst maintaining the necessary levels of information assurance, requires advances in the state of the art for network protocols and algorithms, and a security approach that is radically different to that adopted in the rest of the MOD communications infrastructure. **The need for interoperability between ad-hoc networking systems, both across national forces and across coalition forces, makes research in this field a high priority and a natural topic for international collaboration. This area of research is therefore being pursued collaboratively with the US through the Network and Information Sciences International Technology Alliance.**

The International Technology Alliance

Objectives:

- Research affordable state-of-the-art technologies;
- Promote collaboration between leading industrial and academic organisations in both nations;
- Promote international industrial / academic partnering to facilitate early exploitation of jointly developed advanced technology;
- Promote close working between Consortium members and government scientists to establish an enduring community of technical experts;
- Design in interoperability to reduce future programme risks and reduce the impact of cultural differences.

N*etworked enabled capability*

B2.58 A particular requirement for ad-hoc networks arises from the need to provide persistent surveillance of complex environments. The use of low cost sensors in this mission is dependent upon solving difficult problems of arbitrary array formation, verifying the authenticity and accuracy of the information received from the network, and achieving all of this with very limited power and bandwidth capability. In coalition operations there are major benefits in achieving interoperability such that a sensor network can be built using sensors from all participating nations. This area is therefore a natural area for collaboration and is again being pursued collaboratively with the US through the Network and Information Sciences International Technology Alliance.

B2.59 In order to achieve the NEC vision MOD must be able to use the electromagnetic spectrum to sense the location, activities and intentions of the actors within a theatre of operations; to communicate intent and situation awareness; and to support command and control of distributed forces. This places an increasing military demand upon a resource where the fundamental capacity of the medium is determined by the laws of physics and we therefore need to make far more effective use of frequency and spatial diversity for the deployed systems. In parallel, society and the civil infrastructure are increasingly dependent upon systems which use the same medium to support essential functions.

B2.60 The pressure to increase utilisation of the electromagnetic spectrum generates a need to monitor and manage spectral utilisation, particularly the assignment of frequency allocations to military users. This is a difficult issue because of the limited bandwidth available for the military to transmit an increasing volume of information, and also because the increasing sophistication of adaptive systems, some of which now use complex broadband waveforms that vary the timing and frequency characteristics of the transmitted signal to optimise system performance. Centralised management of spectrum utilisation is becoming more problematical and it would be highly advantageous for military networks to be able to organize frequency utilization autonomously. The use of Cognitive Radio (CR) techniques provides the prospect of achieving this. Military CR requirements include a number of parameters that are not required in civil applications, such as the use of low probability of detection and interception waveforms, RF power management and smart antennas. Therefore MOD will support research into this topic primarily through international collaboration to facilitate deployment of compatible systems throughout a coalition force.

B2.61 Advanced free-space optical communication technologies could also become an important enabler by offering ultra-high bandwidth, lack of channel contention with low probability of detection and secure key exchange. Potential applications range from covert communication links for remote sensors to high bandwidth links for operational reach-back. Free space laser communications for deployment on moving platforms are unlikely to be developed by civil industry. The military requirement would require good pointing and tracking technology, which could be similar to that, required for electro-optic countermeasure systems. This may be an application where MEMS can offer a major system advantage. **The limited production volumes for the optical components make research and development of free-space optical communication technologies an important topic, which will be progressed through international collaboration.**

B2.62 Optical technologies also provide a means for high speed processing of information. In the future, techniques such as "slow" light, opto-electronic correlation and ultra high density optical interconnects will be combined to open up new application areas. These may be integrated with conventional sensing elements or digital components to yield extremely compact and rugged units in key applications. **The civil market for optical processing capability is limited and MOD will support research and development to assess the full military benefit. International collaboration will be sought for the optical components because of the limited production volumes, but MOD will support an onshore algorithm design capability.**

B2.63 With the introduction of NEC information management becomes an essential underpinning technology for a much greater range of military capabilities including, for example, integrated logistical support. However, there are a number difficult underlying technology issues which are of major importance to defence. One such issue is the problem of translation between ontologies which underpin interoperability between coalition systems. Another is how to manage and present information in the best way to the human operator. Both problems require research that crosses traditional disciplines, to enable design of information and security architectures for defence systems that will be compatible across coalitions. This will also allow information management systems to support the human cognitive process, irrespective of whether the user is following standard procedures or is engaged in real world problem solving.

B2.64 **We will progress these problems as a priority within the MOD research programme and we will establish a Defence community of practice, which will embrace academia, RTOs, DTCs, and manufacturing industry, to increase and prioritise UK research activity in this area. We will seek to extend the programme through international collaboration to address the closely related cross-cultural issues.**

B2.65 The principal resource which is required in order to lead innovation in this field is experienced people. This is a common feature for a number of cross-cutting technology fields, and the proposed approach for MOD is expanded in 'Signal Processing'.

The Human as Part of the System

B2.66 Defence technology can only be judged worthwhile if it assists humans to achieve mission success. In practice, and despite widespread acknowledgment that the human is the most valuable part of defence capability, our approach has too often been to consider the human dimension as something of an afterthought. Military success frequently depends upon human ingenuity, insight and agility but this has had little impact upon the way in which we think about and develop technology for defence.

B2.67 MOD faces substantial challenges in this area both in terms of maximising the benefits from an increasingly expensive and scarce human resource, and also in meeting increasingly stringent legislation. To meet these challenges we will need to embed human performance, ethics and care aspects within our capability development and sustainment.

RAF Radar operator

Table 4. Summary of Priority Technologies for Human Dimensions

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
System Engineering	Tools to identify & measure key human factor integration issues in systems and command structures Socio-technical methods and tools	Maintain a world class UK capability	
Modelling & Simulation	Representation of human behaviour and variability in M&S	Maintain onshore capability through collaboration	
Human Behaviour	Understanding of human behaviour Methods and tools supporting Information Operations		Maintain national capability through research collaboration with civil and defence bodies.
Selection & Training	Personality profiling, Simulation technologies	Essential that the MOD develops a deep understanding of its recruitment pool. Simulation technologies for training will be drawn where possible from the civil domain.	
Human Performance	Human cognitive processes Impact of drugs on human performance, Bionics	Cognitive research urgently required to impact current IT development	Technology watch on effect of drugs, maintaining links to international programme through research collaboration
Duty of Care	Health monitoring, Combat casualty care, Nutrition		Maintain national capability through research collaboration and technology watch maintain links to international programmes

B2.68 The UK has adequate access to best practice and guidance on integrating the human element within defence systems but this needs to be disseminated widely and more effectively, not least to platform and system designers. This knowledge then needs to be employed as part of the overall Through Life Capability Management process, including equipment upgrade and technology insertion.

B2.69 **Building on current work in the Human Factors Integration DTC, future investment will be focused on removing barriers to application of well-understood processes. This will aim to provide proven tools that enable systems engineers to consider the human as an integral sub-system rather than as an external, unconnected component.**

B2.70 From a technology perspective one of the most powerful instruments for improving the ability of MOD and industry to deliver effective and affordable defence capability is the use of modelling and simulation. Given the complexities and variability of the human element, high precision and accuracy in modelling is largely unachievable, at least in the medium term. It is most important to understand what can be achieved in human modelling and how it can most appropriately be used.

B2.71 Simulation is increasingly used in training. Consumer demand in the civil computer gaming industry has driven massive advance in hardware and software, much of which is exploitable for defence purposes. Contrary to the commercial market, where increased realism delivers competitive advantage, the requirement within defence is for the minimum level of fidelity required to ensure the mental immersion of trainees in the exercise. **MOD will invest in research to bridge the gap between detailed man-in-the-loop models and large-scale OA simulations.**

Human performance

B2.72 The role and performance of the people within our defence systems will be increasingly tested as we move towards a more information rich, networked environment. A great deal of technical development is taking place to generate, collate, process, disseminate and present information. The algorithms and the technical networks are being designed with only limited understanding of the role that information plays in operational success, especially via human cognition. Human low-level processing of information is often an important component of higher-level cognition, allowing the building of 'mental models' and supporting intuition. Unless information processing architectures allow a regime that supports human cognition, we may find that our information rich environment cannot be exploited properly.

B2.73 On the world stage the UK is competitive in the scientific understanding of cognition and decision-making, but we need to test and exploit this theoretical knowledge through practical application in operational contexts. Information management technologies must anticipate the deployment of UK forces alongside Coalition and collaborative partners, both military and civilian.

B2.74 **The MOD will collaborate closely with major defence coalition partners and Other Government Departments in order to understand, for example, diversity in cultural and operational processes and the impact of these on the capability of the combined force.**

Selection and training

B2.75 The UK needs to maintain its relative level of understanding of issues related to selection and training of personnel and to individual physiology. Steps will be taken to ensure effective interaction between this area and other 'human' areas, especially Human Factors and socio-technical engineering.

Influencing human behaviour

B2.76 Emphasis on effects-based operations has focused attention on the range of ways in which actions of individuals and communities may be influenced and changed. Progress in understanding our own defence capability will contribute to the development of knowledge, technology and methods to influence other groups and communities.

B2.77 **Key areas related to influencing human behaviours such as information operations will be progressed exploiting, where possible, the wider perspective that may be gained through international and OGD collaboration.**

Duty of care

B2.78 MOD has very important individual and collective duty of care responsibilities. Our capabilities in discharging these responsibilities are good, but the legislative and environmental context of military operations and training is changing faster than our developing knowledge.

B2.79 **We need to improve our understanding of the duty of care issues we will face in future and we will therefore maintain a technology watch programme and support this with research programmes undertaken in collaboration with other nations that have similar problems.**

Platforms and structures

B2.80 The majority of the technology issues relating to platforms and structures have been covered in the Sector chapters. However, it is necessary to address the key underpinning technologies.

Table 5. Summary of Priority Technologies for Platform and Structures

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Integrated Survivability	Systems engineering Design Modelling	National capability to: Develop and assess system concepts Design adaptable systems to enable response to changing threats Understand the effectiveness and survivability trade space Assess potential solutions, including evaluation and acceptance	
Power source and supply technologies	Systems design and power management Primary batteries Secondary batteries Fuel cells	National capability in system design UK access to high energy density electrical power sources Expertise to enable minimisation of environmental impact and impact of legislation	
Advanced materials	Low observable materials Platform and personnel armour Smart materials Modelling and design	National capability in: LO materials design and Through-Life support Manufacturing and integration of ceramic armour Modelling to support Through-Life support of advanced materials, especially for certification issues Science relating to intermediate and high strain rate physics	Technology watch for advanced materials Expertise to enable exploitation of smart materials Supply chain for specialist steels

Integrated Survivability

B2.81 Integrated Survivability is the systems engineering methodology to achieve optimum survivability at an affordable cost, enabling a mission to be completed successfully in the face of a hostile environment.

Figure 3. Survivability may be broken down into three elements: susceptibility vulnerability and recoverability

B2 Cross-Cutting Technologies

B2.82 To realise the benefits of an integrated approach to survivability, it must be addressed at a holistic system level. This approach relies on having the necessary Systems Engineering skills. It also requires UK ownership of the systems architecture to enable affordable upgrades through life.

B2.83 **MOD will develop a robust partnership with Industry to develop a systems engineering approach based on open systems with a UK Design Authority. This will enable the UK to develop, sustain, rapidly adapt and upgrade survivability systems to meet changing threats.**

B2.84 It is essential that the UK supplier base has the expertise to:
- Develop and assess system concepts that are adaptable against a background of changing operational scenarios.
- Understand the effectiveness and survivability trade space for designs, in particular to understand the implications of exploiting COTS technology.
- Assess potential solutions, including evaluation and acceptance.
- Optimise technology insertion and design adaptable systems.

B2.85 The present UK industry capability on Integrated Survivability is patchy with some areas of strength, for example in tactical fixed wing and maritime areas. UK defence primes have a good understanding of many of the associated technologies, with specialist expertise and tools in lower tier suppliers and RTOs. These are supported by an extensive SME base. However, it is important that a systems engineering approach to Integrated Survivability is developed in the UK supplier base. **MOD will continue to support a research programme that has developed a sound systems engineering approach addressing all environments, enabling MOD to provide leadership of this developing topic.**

B2.86 Successful development of a systems approach to survivability requires the adaptation and development of cost-effective models that predict the consequences of military operations and account for the success of mitigation measures. Existing modelling and simulation tools require further development and there is potential to develop further the synthetic environments used for through life support of systems based on open architectures. **Currently, MOD has the lead on tools to assess Integrated Survivability and will focus effort on transferring these tools to industry, to enable industry to provide the optimised capabilities that MOD requires.**

B2.87 Tools and methodologies for rapid evaluation and acceptance need to be developed to include Test and Evaluation (T&E) capabilities from Systems Integration Laboratory (SIL), through Synthetic Environments to Live Fire. Advanced databasing techniques coupled to rapid re-programming of equipment could be very effective in improving our rapid response capability.

B2.88 Current and future changes in operational priorities are leading to a significant convergence of threatening circumstances between different platforms, e.g. the increasing 'asymmetric' threat to maritime forces in the littoral is similar for helicopters in all operations. Consequently, there is scope for substantial synergy in technology development to support different types of platform and environment.

B2.89 In summary, the ability to design, sustain and rapidly adapt systems to meet emerging threats is an important national capability. MOD recognises the need to continue to invest in this area as there are few civil market drivers and export potential is affected by the sensitivity of some of the technologies. Integrated survivability is an area where there is much potential for exploitation of common technologies across different capability areas and increased system receptivity, through life capability management and coordinated investment will unlock much potential military advantage.

B2.90 MOD will work with defence industry and government stakeholders to investigate what opportunities can be created by a more Through Life Capability Management approach to integrated survivability, identify the best opportunities for technology demonstration and establish what benefits are offered by exploitation of common technologies across different environments and capabilities.

Power sources, power management and supply technologies

B2.91 The availability of both electrical and motive power is of the highest importance to modern military operations, requiring a systems approach across the military logistics supply chain.

B2.92 At the platform level there are three aspects to optimising available power:
- The power source(s).
- Power management.
- Reduced power demand.

B2.93 An integrated systems approach is required to address both better power management, and to improve the efficiency of systems. Both aspects are actively being researched in a number of MOD programmes and are specific topics for the SEAS DTC.

B2.94 In addition to the increasing demand for electrical power for electronic systems, there is a trend towards increased use of high power electrical systems such as electric actuation, electric control and even electric prime movers, in defence platforms. This is in addition to more advanced concepts such as electric armour and directed energy weapons. Major demonstrator activities are already underway in areas such as electric ships and hybrid electric drives. Projects such as the AeIGT More Electric Aircraft project are seeking to develop more efficient electrical ancillaries integrated with a gas turbine prime power source.

B2.95 Realisation of more electric platforms requires compact, efficient, lightweight, temperature and vibration tolerant power electronics. Successful implementation of this change in approach requires that major advances in power electronics and electronic packaging performance be achieved since current technology cannot meet the full requirement. There are overlaps with the electronics packaging requirements discussed under 'Sensors and Countermeasures'.

B2.96 The development of reliable health management systems for diagnostics and prognostics also has the potential to improve electrical power system availability and reduce whole life costs. Systems are currently of low maturity and work is required to improve many aspects, including sensors and intelligent fault detection and diagnostic systems. Much of this technology will be driven by the civil sector, but is of great importance to MOD. **MOD will establish a technology watch programme to understand and, if possible, influence future developments.**

B2.97 It is anticipated that batteries will remain the major source of portable electrical power for another decade at least. It is unlikely that UK defence investment can make an impact other than in the adaptation of technologies developed for civil markets to meet specific high priority defence needs. However, high energy density primary batteries are largely military-specific, and MOD will invest in this area to improve and retain capability.

Ammonia borane pellets
A key issue for any potential Fuel Cell concept is the source of hydrogen, transportation of the fuel is a particular military issue. QinetiQ have developed a portable hydrogen generator system utilising a chemical hydride (Ammonia borane). Ammonia borane pellets are sequentially decomposed to provide an electrical load-following capability. Energy storage can be scaled-up by increasing the layers of pellets.

B2.98 Fuel cells may offer a step change in the efficacy of portable power supplies in the future, and offer the potential for near-silent power on the battlefield. It is as yet unclear which type of fuel cell will make the breakthrough to practical utility. While the basic technologies are available and there is a great deal of civil investment in this area, there are significant integration issues for military systems that need to be overcome.

B2.99 **MOD will consider how best to maintain UK access to high energy density batteries and will maintain an active programme of technology watch on secondary batteries and other small and portable power sources to ensure that any emerging technologies are identified and investigated at the earliest opportunity.**

B2.100 Increased rationalisation of battery types across different equipments is an important objective. Significant operational, logistic and cost gains may be made by ensuring that coherent advice and guidance on energy sources and power management is available. **MOD will carry out a study to establish what level of technical support is required, and will form and maintain a body of expertise to support this need.**

B2.101 Reserve batteries – having ultra-long shelf life and ultra-high reliability on use – are not seen as an area in which great advances are required, and manufacturing capability exists for peace time requirements. However, there are very few civil applications for reserve batteries, leading to a major supply issue in times of conflict. **MOD will work with suppliers of reserve batteries to consider how best to maintain the required reserve production capacity.**

B2.102 Environmental impact of electrical and motive power sources both in terms of emissions and use and disposal of toxic materials are also going to be increasing important. Future power systems will be expected to have reduced emissions. Efforts to achieve reductions in CO_2; NO_X, SO_X and particulate emissions reduction will be required in the medium to long term. Carefully consideration is also required of trends in regulation such as removal of cadmium from power systems and recycling of batteries. Of equal importance is the need to address fuel efficiency and power management to mitigate rising fuel costs.

B2.103 **Through these programmes of technology watch on power sources, MOD will monitor developments in the civil sector, maintain sufficient expertise to minimise environmental impact and understand implications of legislation.**

Advanced Materials and Structures

B2.104 Development and exploitation of advanced materials underpins many aspects of the design, development and manufacture of military platforms and equipment. However, MOD's investment in materials and structures has decreased markedly in recent years as developments are increasingly driven by global civil markets, and commodity products are often adequate for our needs. The table below shows those areas where there are defence specific issues that need to be addressed, including where there is concern over materials supply in several critical areas. In addition, MOD will continue to ensure that it is well placed to understand and exploit new materials and approaches to structural design where necessary.

B2.105 From a defence perspective, advanced materials and components may be divided into four main topic areas:

- Low observable materials (EO, IR, RF and acoustic).
- Platform structural materials for protection and through life support.
- Smart materials and active structures.
- Structural modelling, design and dynamic performance.

Table 6. Summary of Priority Technologies for Advanced Materials and Structures

Category	Priority Technology Area	Key Defence Specific Issues
Low observable materials	EO, IR, RF and Acoustic	· Support UK manufacturing capability in underwater LO materials · LO materials design trade-space - performance vs. operability (shape, volume, mass) vs. affordability · especially of multifunctional materials combining pan-spectral stealth with high temperature applicability and structural functions · Through-Life support
Platform structural materials	Polymeric materials	· Enhanced temperature capability · Enhanced protection / decontamination from CB agents
	Composite materials	· Reduce cost of polymer composites structures through new materials & manufacturing processes · Enhanced ballistic/spall performance without structural degradation · Enhanced resistance to blast and shock · Smoke and toxicity improvements for maritime applications
	Metallic materials	· Through-Life affordability · Specialist armour supply issues · Increased structural efficiency e.g. reduced density, novel structures
Smart materials and active structures	Multi-functional materials and structures	· Novel materials offering enhanced or integrated functionality through active, adaptive or responsive characteristics. · Innovative system designs exploiting integrated multi-functional materials and structures.
Structural Modelling, Design and Through-Life support	Structural modelling, design and simulation	· Structural analysis & design techniques for Through-Life support of structural integrity, survivability & sustainability · Enhanced modelling capabilities for novel fabrication and joining technologies for residual stress/ distortion · Integrated holistic modelling to support certification and classification
	Non-destructive evaluation and health monitoring systems	· Support for ageing platforms, enabling life extensions based on condition based maintenance · Health monitoring systems for future platforms, or retrofit, to minimise platform downtime during maintenance
	Corrosion and environmental protection	· Reduction of life cycle costs and improve maintainability & life extension by understanding degradation processes and protection
	Environmental issues	· To introduce environmentally acceptable materials & processes to ensure system/component availability and reliability e.g. Cd, Cr and Pb-replacement technology, environmental legislation

B2.106 In order to maintain the broad range of technical capability needed to support UK defence needs, **MOD will maintain a very active programme of technology watch. This will be done by stimulating the structural materials research and development community, particularly in academia and RTOs, with important technology challenges where either new materials or those developed for other markets could give defence benefit.**

B2.107 **MOD will work with the materials community across industry and Government – through the Defence and Aerospace National Advisory Committee, the ATSG[1] and Mats IGT[2] – to establish opportunities for collaboration in the UK (through the OSI funded Technology Programme, and EPSRC programmes). The materials supply issues described below are a common theme across Europe so there is also a strong driver for collaboration with European partners.**

B2.108 In addition to this active technology watch there are five areas of defence specific technology where the UK needs a national capability. In these areas MOD will work with the materials supply chain and systems integrators to consider how best to influence the development and availability of technology:

- **Ceramic Materials**. The UK depends on supply of material on a COTS basis. However there are key areas where expertise is required in the UK, for example in the design of lightweight and other special armour; components for arming, and fusing weapons (including nuclear weapons); electro-ceramics for sonar systems; and ceramic composites (including carbon-carbon) as thermo-structural materials. **MOD will work with the supply chain to establish the viability of on-shore manufacture of specialist ceramics.**

- **Specialist Armour Steels**. The MOD has a requirement for a surge manufacturing capability, for which there is currently no on-shore supplier. MOD will work with the supply chain to understand the viability of on-shore manufacture of specialist steels for armour and consider the opportunities for European collaboration.

- **Intermediate and High Strain Rate Physics.** The UK needs to understand the fundamental science both to predict weapon performance and to enable critical decisions to be made on weapon safety and life. MOD will work with the research councils to grow and maintain expertise in the field of intermediate and high strain rate physics.

- **Signature Control Materials**. Effective signature control materials are a key enabler to the capability to manufacture, repair and through life support of Low Observable platforms. The Maritime sector analysis also identifies a specific requirement to sustain signature/materials expertise in the area of low signature submarines as a key national capability. A UK onshore capability is vital in these areas; MOD will focus investment on a system application led approach, and work with industry and academia to ensure access to the required expertise in signature control materials in the UK.

- **Composite materials**. Understanding and modelling of structural and dynamic issues, at molecular, material and structural levels are vital for effective assurance, test, repair and disposal. MOD will invest in the research programme to explore and develop integrated materials modelling and certification methods.

The Physical Environment

Introduction

B2.109 Accurate and timely prediction of the state of the natural environment is key to delivering decision superiority. The time scales of interest range from 1-48 hours for tactical mission planning, through weeks to months for strategic planning, to decades for equipment design or force structure decisions. The move to effects-based operations and the integration of forces through NEC demands that forecasts are available for the marine, land, air and space environments. The SDR New Chapter emphasis on expeditionary operations and rapid response demands that accurate environmental information (EI) is quickly available for anywhere in the world.

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[1] *Aerospace Technology Steering Group part of the Aerospace Innovation and Growth Team, responsible for delivery of the National Aerospace Technology Strategy Implementation Report, 2004.*
[2] *The Materials Innovation and Growth Team published its Strategy for Materials in June 2006.*

Table 7. Summary of Priority Technologies for the Physical Environment

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Earth Observation	Space based sensors	The UK should maintain current levels of expertise in order to retain influence over future earth observation missions, particularly in Europe	Activity in Earth observation will remain an essentially international exercise – especially with respect to exchange of observational data
Numerical weather prediction	Supercomputing for environmental modelling Capture and exploitation of theatre-relevant observations	UK will continue to buy supercomputers for environmental modelling from the global marketplace In order to meet the needs of national forces, the UK will maintain world-class expertise in this area.	Some possibilities for gaining access to international resources

Earth observation

B2.110 Earth observation by satellite-borne instrumentation and by novel terrestrial, airborne and marine sensors enable global observations of the Earth's surface, deep ocean and atmosphere. A range of active and passive sensor technologies is involved, primarily but not exclusively concerned with remote sensing. The UK has historically been an active participant in the development of ground- and space-based sensors, contributing instrumentation to both US and European missions. The expanding capability, attractive economics and shorter design-to-deployment times of small satellites will place a high premium on lightweight sensors.

B2.111 The UK is highly dependent for operational environmental observations upon the US funded activities referred to above. There is a long history of international exchange of observational data with the US for both civil and defence needs and MOD will seek to continue this relationship.

Theatre-relevant observations

B2.112 The technology required to extract the benefits of in-theatre observations involves development of both sensors and the downstream chain of data assimilation and processing.

B2.113 The USA remains the largest operator of Earth observation systems, particularly polar-orbiting satellites. Through the EUMETSAT organisation Europe has, for many years, contributed members to an international constellation of meteorological geostationary satellites (the Meteosat series). European countries, either alone or in concert, have launched a range of earth observation satellites, primarily for research purposes. The UK has been an active participant in developing sensors for European Earth observation satellites.

B2.114 For operational forecasts and climatology of conditions above the stratosphere the USA is also the largest operator of satellites and ground based instrumentation of ionospheric electron density and the high energy particle environments of space. The European Space Agency also has a developing programme, primarily directed at the high energy particle environment.

B2.115 **There is no need for the UK to replicate technology deployed by the US, but in order to remain an active and full participant in international activity MOD will maintain expertise in niche areas such as technologies for in-theatre observations.**

Environmental modelling

B2.116 A strong base of scientific understanding and skills is required in order to develop and validate environmental models, and to design and exploit the outputs of terrestrial, marine and space-based sensors. No single institute or country can claim a monopoly of skills or knowledge since much of the output is the result of shared effort. Nevertheless the UK can justifiably claim to be one of the world's leading nations in environmental research and modelling.

B2.117 **MOD recognises the importance of participation in environmental research and funds much of the underpinning research infrastructure. The present balance of funding of underpinning environmental research in the UK meets MOD's current needs. Over the next twelve months MOD will assess how best to maintain its investment and maximise exploitation in this area.**

Supercomputing for environmental modelling

B2.118 In order to develop, validate and run these increasingly complex environmental models supercomputing technology is required. Leading edge supercomputing technology for environmental modelling is held by Japan and the USA, a situation that has pertained for a number of years.

B2.119 The key issue for the UK is not control of supercomputing technology but access to supercomputing resources. UK access to supercomputing resources meets MOD's current needs but the cost of staying in a competitive position with respect to the supercomputing power available to other major environmental modelling centres, has increased substantially. The problem may be partly solved by gaining access to resources, such as Japan's Earth Simulator, via international collaboration, but the UK would not have priority access to these resources and security implications would restrict exploitation for the UK Defence purpose.

B2.120 **During 2007 MOD will, in partnership with other Government stakeholders, assess the level of investment that it should make in supercomputing for environmental modelling, in order to meet front line and wider defence needs.**

Technology to Enable Through Life Capability Management

B2.121 To achieve military advantage MOD systems incorporate ever more complex functionality and connectivity and much of this is embedded in electronics and software. To implement these systems, MOD must ensure that the enabling science and technology is capable of delivering and supporting these systems and also that the integrity, robustness and safety of these systems, including any human or software elements can be assessed and assured efficiently and cost-effectively.

B2.122 The increasing life expectancy of major platforms generates an increased need for equipment and systems to be flexible to meet unpredictable demands, adaptable, and capable of continuous upgrade and rapid technology insertion. As system lives extend to over 30 years we need to design and procure systems that allow much greater flexibility for just in time adaptation at sub-system and component level to meet emerging needs or to allow novel deployment with agile forces.

B2.123 However, to date, the effect of longer-lived military platforms and systems with increased intervals between new generations has been to inhibit technology insertion and reduce our ability to respond to new requirements. In contrast, asymmetric adversaries demonstrate their ability to harness new technology rapidly and the tempo of emerging threats is accelerating.

B2.124 A further important factor driving the need for technology insertion is the need to replace and upgrade the increasing number of standards, components and sub-systems that, while used in defence systems, are developed primarily for the civil markets and hence exhibit the short life cycles and rapid obsolescence characteristic of consumer products.

B2.125 To maximise the benefit that technology contributes to Through Life Capability Management (TLCM) of defence systems we must have:

- Procurement approaches that are based on TLCM.
- Enterprise models for research, development and exploitation that recognise and use the fact that cross-cutting technologies provide advantage across multiple capabilities.
- Regeneration cycles and technology insertion opportunities that can exploit the pace of advance in cross-cutting technologies and that are not determined by platform lifecycles.
- Modularity, open architectures and assurance methods to reduce the cost and time involved in inserting technology and upgrading systems.

B2.126 To make rapid progress towards a through life approach to technology and capability management the necessary technologies, approaches, skills and processes need to be developed, exercised and improved. There has been good work that we can learn from, examples being the open architecture approach to sonar and the Jaguar aircraft upgrade programme, but some highly visible 'early adopter' projects will add impetus.

B2.127 **MOD will work with industry to build on the work already done in the MOD research programme, through the Technology Insertion Major Programme Area, and transition this work into supporting real 'early adopter' acquisition projects. MOD will seek to use the existing DIS Pathfinder projects to provide 'early adopter' vehicles for developing and testing new approaches to technology insertion.**

Trafalgar class submarines currently undergoing a mid-life upgrade of sonar system

Table 8. Summary of Priority Technologies for TLCM

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Open Systems & Architectures	Design and integration of open systems Demonstrators and components serving multiple military platforms and systems Shared access to common test-beds for evaluation, integration and spiral upgrade	National capability to own maintain and where necessary develop standards	
Simulation & Modelling	Model sets to support cradle to grave TLCM Synthetic systems/environments exercised through upgrade cycles		National capability, exploiting collaboration, accessible to MOD and industry, Common Engineering Model framework for unified weapon modelling
Acceptance, Certification & Assurance	Technology solutions for affordable assurance of software CAD designs and interface specifications	National capability accessible to MOD and industry	
Electronics Hardware	Management of obsolescence Reliability of Electronic systems	Intelligent customer and user	
Geolocation and Synchronisation	Accurate and affordable (atomic) clocks Accurate and robust position measurement Standards and transformations for interoperability	Access to technology, UK ownership of system design and standards	

Open Systems and Architectures

B2.128 Open architectures are crucial if we are to exploit the innovative technology in UK universities and industry for the benefit of defence. Across defence, individual systems need to be developed within an architecture that enables straightforward integration of future equipments and flexible reconfiguration. Individual systems need to adopt a modular architecture, with clear partitioning of sub-systems and functions, if we are to enhance military capability through improvements in subsystems rather than by acquiring new systems. We will also discourage the use of proprietary networks and interfaces within equipments to achieve this.

B2.129 The adoption of an open architecture approach also facilitates the reuse of military subsystems and cross-cutting technologies across a range of military platforms and systems. Open architectures need to be standardised, agreed and widely used to maximise this potential benefit.

B2.130 MOD has some notable successes in the use of open architectures, an example being the open architecture approach to sonar systems, but there is probably still much that MOD could learn from the open systems being developed for civil markets. Even in systems regarded as disposable, widespread use of open and standardised architectures can deliver great reductions in cost and risk, consumer electronics providing an excellent example.

B2.131 Effective TLCM also needs a clear understanding of the interrelationships between requirements, contractual and commercial approaches, the system architecture, commercial and ownership costs. Building on architecture models, business models need to be developed in order to understand the impact of planned and potential change on a system and capability, including impact on the supply base and training needs. The central collation of data and metrics on project costs and schedule overruns is vital in order to fully understand the scale of the software related issues to MOD, and also to identify at which stages of projects risks are met.

B2.132 The development of the necessary tools and techniques is an important component of the systems engineering approach but the value of these technical capabilities will only be realised if they are embedded into the defence enterprise together with the culture, skills and processes being addressed as part of the DIS implementation. The MOD Integration Authority is coordinating activities aimed at improving MOD's use of systems engineering best practice. Systems Engineering is central to the delivery of defence capability and the UK needs on-shore expertise on all aspects of Systems Engineering.

B2.133 To make an open systems approach effective MOD will take ownership of the overall defence architecture design, and be responsible for ensuring appropriate architectures and standards are in place. MOD will also provide a leadership role in working with the Defence community to develop, agree and communicate what these architectures and standards are and also what providers need to do to ensure that they can interface with them.

Scientist working on sonar array

Modelling and simulation to support TLCM

B2.134 A coherent 'cradle to grave' modelling and simulation toolset, used consistently by stakeholders across MOD, industry and academia, will develop a shared awareness of requirements, opportunities and constraints facilitating top-level trade studies and supporting Through Life Capability Management. Integrated modelling is potentially a powerful tool based on a hierarchical approach (see diagram below) of detailed simulations (physics and chemistry based models) linking to engineering models, finally coupled to operational analysis tools including synthetic environments.

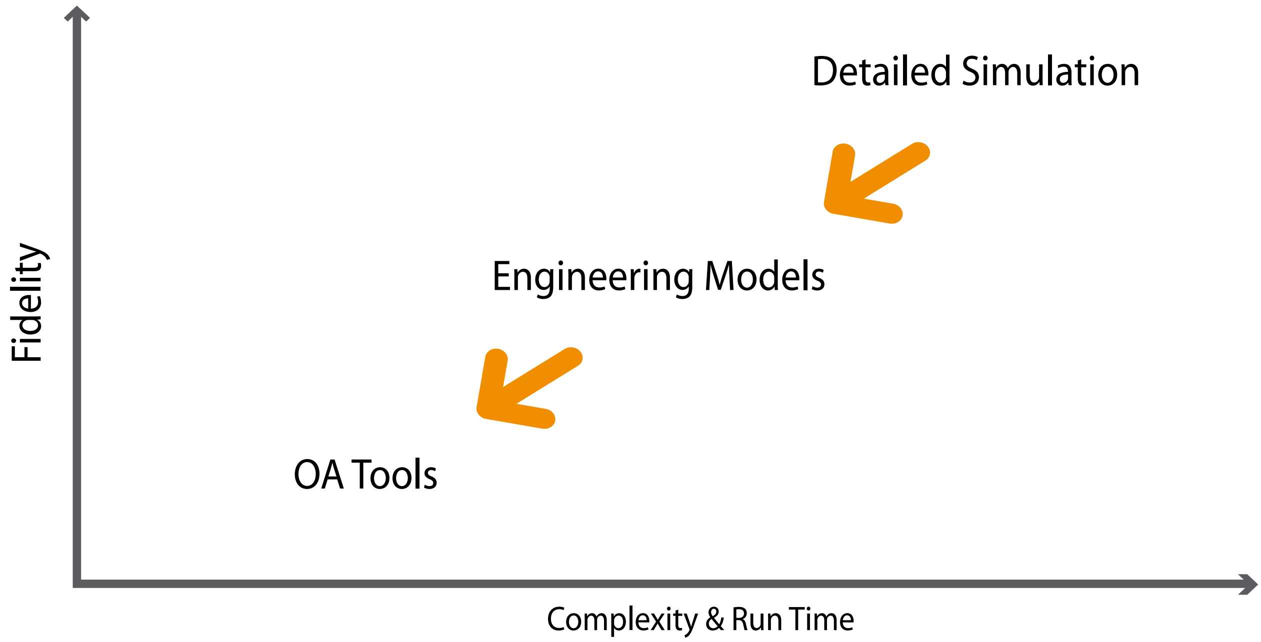


Figure 4. Hierarchical approach to integrated modelling

B2.135 We are currently working with industry in the Guided Weapons Tower of Excellence and with international partners to share a common engineering model framework for unified weapon modelling as part of such an approach. The integrated modelling approach has been used to assess the military implications of blast in an urban environment and supported the acquisition of the Anti-Structures Munition.

B2.136 **MOD will extend the integrated modelling philosophy to other areas to support design, assessment, through life management and support to operations.**

B2.137 Our modelling and simulation toolsets need to be informed by, and developed within our overall defence architecture to ensure that future equipments will fit together and work in a way that supports flexible upgrade and reconfiguration to meet emerging threats and needs and must also include the human elements of the system.

B2.138 One important aspect of this modelling and simulation is to facilitate efficient and cost effective acceptance and assurance of our systems. We need to be more joined up in the way we assure our systems progressively across the whole lifecycle. This involves mainly modelling and simulation at the front end, test rigs and experimentation in the mid-stages, reference centres for technical integration and acceptance with user trials and effectiveness measurement at the operational end. A more through life approach to modelling and simulation will support the integration of these development and assurance activities.

B2.139 A key to successful implementation of systems engineering is the quality of the metrics used to indicate the progress of programmes. More work is needed to understand metrics better using data that are easy to collect, are repeatable, give information that can be used in real time to manage complex programmes and are applicable to the contracting process in the UK.

B2.140 **MOD will develop an infrastructure framework that encourages and supports adoption of a through life modelling and simulation approach that can be assured by both MOD and industry and used to support their technical and business processes, including operations and training.**

B2.141 In addition to this development the integration of experimentation, analysis, test and training facilities with shared assets such as model and terrain databases repositories is a strongly emerging requirement for defence. The provision of a joined-up defence wide capability will need close interaction between MOD and industry.

B2.142 **MOD will work in collaboration with industry, using existing fora such as the Synthetic Environments Tower of Excellence and initiatives including the Integrated Modelling and Simulation Support for Acquisition (IMSSA) project, to develop a joined-up defence wide modelling and simulation capability. Our approach will be based on using open standards and architectures, exploiting COTS technologies where practicable and developing and using common modelling and simulation components.**

Acceptance, Certification & Assurance

B2.143 More efficient and affordable acceptance, certification and assurance of military systems are essential to harness the benefits of TLCM and, in particular, technology insertion. The increased use of open systems and architectures and through life modelling and simulation will play and important role in this, but specific technologies solutions are required in some areas. By far the most important of these is software, particularly for safety critical and other high integrity applications.

Software

B2.144 Software is the critical enabling technology for modern platforms and for Network Enabled Capability (NEC). The DPA currently spends over £1Bn on its £7Bn annual spend on software and the proportion of spend on software will only grow with the advent of NEC. More of the software functions will become safety related as communications software and mission systems become an integral part of sensor-to-shooter weapons targeting systems.

B2.145 The growth in the complexity of software has far outstripped the increases seen in other physical systems: Typhoon and JCA have 80-90% of their functions enabled by software. However, the resulting rapid increase in dependency on software to provide critical functions has outstripped the UK's ability to cost-effectively 'own' military software.

B2.146 Software should also represent a major enabler for TLCM, allowing rapid system growth and reconfiguration to meet rapidly evolving operational needs via software upgrades, rather than hardware changes. However, the reality is that software, especially in safety critical applications, often takes too long to produce, and the acceptance and clearance to service procedures are very costly and time consuming, and the development time and cost are difficult to estimate accurately which means that upgrade of the software within an equipment is often seen as a last resort to meet evolving military requirements.

B2.147 Unless significant steps are taken to coordinate the management of software development and ownership within MOD, the risks to project delivery and upgrade will increase and the TLCM opportunities presented by software enabled and open architecture systems will not be realised.

B2.148 For the particularly difficult problems that MOD faces with high integrity and safety critical software (HI&SCS) there is much overlap with civil sector requirements and much to be gained by aligning military practices with civil solutions. However there are areas where military software requirements are more demanding:

- **Criticality –** Military aircraft may be unstable, making the flight control systems more critical than in their civil counterparts.
- **Autonomy –** Systems such as stand-off weapons and UAVs may need to operate without a "man in the loop".
- **Adaptation –** Control systems may need to adapt to unprecedented situations.
- **Evolution –** Systems will need to evolve rapidly, requiring the rapid insertion of new functionality.

Typhoon cockpit

B2.149 The issues presented to defence by HI&SCS are set to increase, driven by a number of factors:

- **Growing stringency in safety requirements.** The military air system safety targets have recently been improved by a factor for three for future aircraft systems and will be raised by a factor of four by 2010. The improvement required for this step change will largely fall to the software with a resulting increase in the levels of proof of safe operation needed to support certification.
- **Networking and the growth of interconnectivity.** The implementation of NEC potentially represents a potential discontinuity in complexity, as interconnectivity between platforms and systems increases exponentially with networking.
- **The Increased Extent of High Integrity Functionality.** With the advent of NEC, and also the rise of system autonomy, many more system functions which are currently mission critical will have to meet high integrity or safety requirements.

B2.150 A panel, consisting of experts from MOD, industry and academia and sitting in support of the DTS, has highlighted the following challenging HI&SCS research goals for the UK to achieve by 2020:

- For systems equivalent to today's levels of complexity, the cost of development should be 25% and development time should reduce to 50% of current values.
- Predictability of development time and cost should be accurate to 10%.
- New systems should be developed in the same time and cost, despite a predicted 5-fold increase in complexity.
- A reduction on sustainment costs to 1% of initial development cost per annum.
- A linear increase in cost with scale, despite exponential increases in connectivity.

B2.151 Attainment of these testing HI&SCS 2020 goals will only be met via coordinated progress on a number of fronts, including the technical, process and commercial fields.

B2.152 The creation of the safety case and its constituent evidence has to become a product of the key stages the HI&SCS development, rather than a subsequent additional process. The creation of safety case evidence also has to be increasingly automated. Again, improved architectural modelling needs is key here and core safety evidence needs to be produced early at the model level. In the shorter term, greater understanding of the role of evolving validation and verification technologies and their applicability within safety cases will allow the right business model for evidence creation to be used.

B2.153 Current MOD research investment in safety critical and safety related software is of high quality and targeted at high payoff areas such as modular certification, but represents a fraction of a percent of the overall defence software spend. The need for cross sector coordination and the promotion of consistent application of advice within projects has been recognised by MOD which is establishing the Software System Engineering Initiative (SSEI) as a multidisciplinary body of expertise. The SSEI will provide a sound foundation for a coherent and centralised approach to pan-MOD HI&SCS management.

RAF technicians servicing a C-17 engine

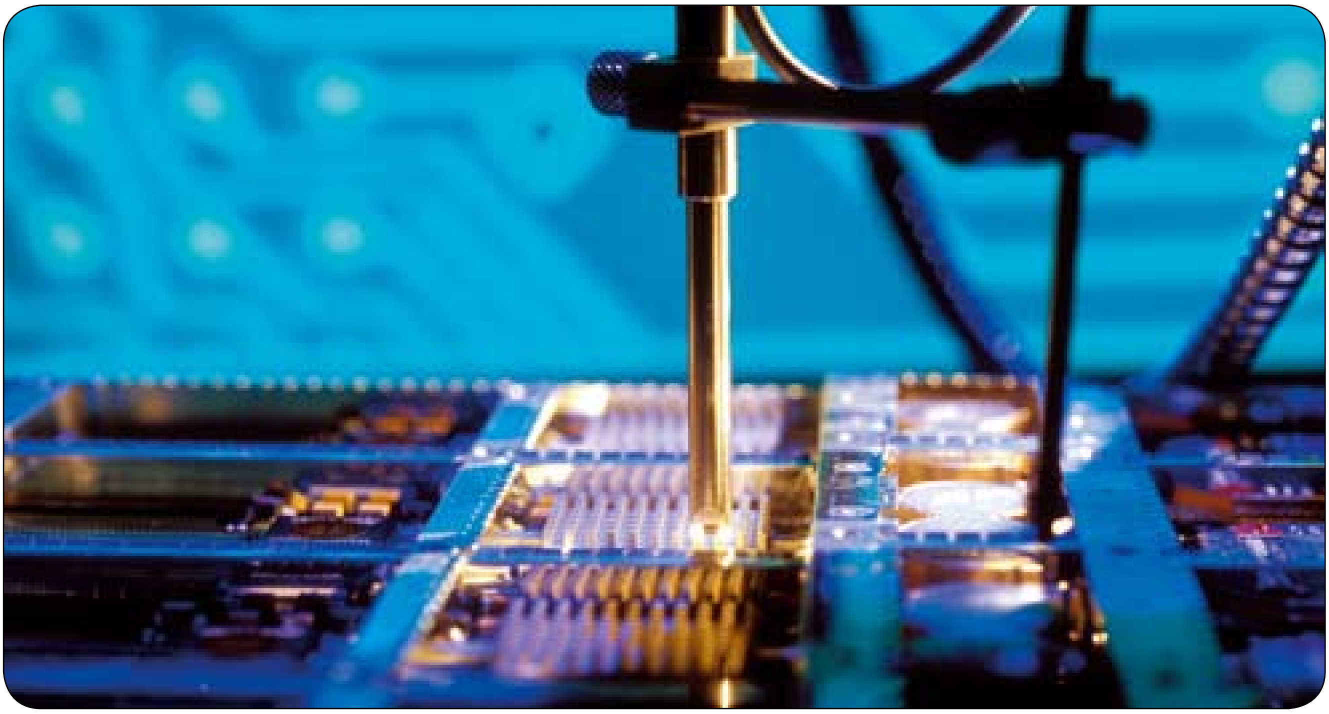
B2.154 **MOD will build on the Software Systems Engineering Initiative being driven from its research programme to research technology solutions for assuring software and to build, maintain and refresh a body of experts able to provide expert and consistent advice to MOD, in particular into procurement and support projects.**

B2.155 In addition to the important area of software discussed above, there are other aspects of Acceptance, Certification & Assurance that have impact across defence sectors. A good example is provided by Electromagnetic Compatibility (EMC) testing. Ensuring robust Electromagnetic Compatibility is important to the systems engineering, survivability, and integration aspects of all systems and platforms. The increase in proliferation of electronic and electrical systems set against a backdrop of increasing potential electromagnetic disturbance and interference leads to very challenging constraints. EMC testing has evolved in separate disciplines for air, land and sea platforms, with air platforms, due to the safety critical nature of EMC disturbances, leading on the research front. An increasingly integrated tri-service environment will pose even greater challenges to ensuring EMC.

B2.156 EMC expertise throughout MOD and Industry is in a state of decline and given the challenges faced in ensuring the survivability of systems and platforms there is a need to maintain UK expertise in EMC. **MOD will invest in research in this field as necessary to develop new cost-effective and comprehensive ways to produce compliant, robust and survivable platforms. This effort is likely to include improvements in modelling and simulation, test and evaluation and cost-effective hardening and protection technologies.**

Electronics Hardware

B2.157 Electronic materials and components have had huge impact on civil and defence systems over the last 20 years. None of these changes has been the result of a radical new technology over the period: the impact is the result of incremental developments of existing technologies, particularly silicon, coupled with developments in chip design and system architecture all driven largely by civil markets. This trend of great performance improvements will continue over the next 10-20 years, again driven almost entirely by civil markets.



PCB Manufacture © BAE Systems

B2.158 The biggest issue facing UK defence in the field of electronic materials and components is access to existing and future component technologies. Even silicon circuits, widely regarded as commodity products, present difficulties because:

- Fabrication will be concentrated in fewer and fewer foundries of increasing production capability and increasing cost of ownership. Direct access to state-of-the-art processes will become impossible for small-volume specialised requirements, which will have to rely on general purpose components in the absence of a specific facility. State of the art processing is less and less available for wide temperature range components as required by many defence programmes, restricting the operational window for defence products containing merchant parts.

- At present most companies procure Application Specific Integrated Circuits (ASICs) through silicon design houses that maintain close links with major foundries in order to obtain access to state-of-the-art technologies. At present this supply chain works effectively, but may become more difficult as the number of foundries decreases.

- The cost of wafer runs is increasing, partly as a result of the increased cost of design and mask making, but also because of the increasing sizes of wafers and wafer batches. Shared mask sets reduce cost, but also reduce the security of IPR, and affect programme schedules.

- The time scales for the introduction of new generations of silicon technology is very rapid, although this pace of development may slow as the technology approaches fundamental physical limitations, and the contrast between the time scales of military procurement and technology development will be an increasing concern.

B2.159 There is little that the UK can do to affect the source of these difficulties since they are driven by market pressures far larger than any that defence markets can exert and our only solution is to mitigate the problems through a more flexible approach to technology insertion, upgrade and qualification.

B2.160 Future developments will concentrate on innovative applications and the integration of other technology and materials on silicon to increase/improve functionality. Examples include CMOS image sensors with micro-lenses, microdisplays (liquid crystal and light emitting polymer), 3D interconnects for increased density or mixing technologies, MEMS on silicon, biology on silicon, sensor integration with IC technology and nanotechnology on silicon. This activity also includes the development on innovative packaging as standard electronic packaging will not always be appropriate.

B2.161 A number of specific technologies, already under development, are expected to become of major importance over the next 10-20 years. Nanotechnology provides a base for a large number of applications, both military and civil. In general the pattern of exploitation differs from silicon in that following prototype development in conjunction with a University or technology provider, industry sets up specific manufacturing lines for components of interest. It is unlikely that this will change in the medium term because the physical length scale of the components is relatively coarse on the scale of silicon fabrication, and so fabrication equipment is currently affordable. The DTI initiative in this area is an important step. It is likely that defence will not have major difficulties in securing supply of these novel components. Future nanoscale technologies are expected to include silicon structures at nanometre geometries and in the longer term this will require state of the art machines and raise issues of UK defence access similar to those discussed above for current silicon circuitry.

B2.162 The UK defence community needs to remain aware of the latest approaches and developments in the reliability of electronic systems. Although specific topics can be identified, the main focus for TLCM should be on physics-based modelling and prediction of failure in electronic (and other) devices through a comprehensive network of universities and industries. The issues of reliability extend throughout the electronics industry and topics of relevance to defence include: the problems of achieving the high-reliability needed for defence and aerospace components in the face of continued reduction in device dimensions, improved die interconnects, lead-free interconnects, reliable high temperature packaging, package degradation monitoring, high-temperature passives, rapid reliability testing, and reliable non-hermetic electronics and photonics packaging. **MOD will ensure that improved methods for establishing and specifying the reliability of electronics systems are reflected in procurement activities.**

Geolocation and Synchronisation

B2.163 A recurrent theme throughout the development of this strategy is the increasing importance of accurate geolocation and synchronisation. The technologies underpinning geolocation, temporal synchronisation and accurate navigation have not been treated by MOD as a high priority in recent years. Given the increasing focus on, for example, increased networking, autonomous operation and integrated logistics, more accurate and consistent measurement, recording and exchange of positional and timing information is a truly cross-cutting technology with potentially very high impact for defence.

B2.164 To maximise the benefits from networked systems we need approaches to geolocation and synchronisation that encompass and enable the whole defence system of systems and that are not just optimised and robust within individual parts of the system.

B2.165 MOD will establish an MOD/Industry Community of Interest for geolocation and synchronisation to define what needs to done on both organisational and technical axes. This will focus on the requirement for, and benefits of, more accurate measurement and control of geolocation and synchronisation.

B3 C4ISTAR

Introduction

B3.1 C4ISTAR technology is central to our ability to command, control and provide mission critical, actionable intelligence across all levels of the UK's armed forces. It is at the heart of delivering a Network Enabled Capability (NEC).

B3.2 In support of this, the Defence Industrial Strategy identified the need for the UK to retain sufficient expertise to:

- Understand C4ISTAR capability requirements and develop future concepts
- Develop user and system requirements
- Design, integrate, modify and assure overall systems of complex networks and communications with the ability to interoperate with a wide range of partners in support of operations
- Develop solutions across all Defence Lines of Development
- Assess the global marketplace
- Conduct research into areas that are not cost effective or suitable in the global marketplace
- Pull through successful research into in-service and future systems
- Test and evaluate systems
- Provide through life support to UK equipment – including modifications and technology insertion to facilitate upgrades and obsolescence management
- Maintain custody and the integrity of the increasing quantity of national military and intelligence data

B3.3 At the highest level UK MOD needs the ability to define future C4ISTAR capabilities that will deliver improvements in military capability enabled by NEC. In pursuit of this aim we shall take a through-life capability management (TLCM) approach[1]. For C4ISTAR capabilities, this approach additionally demands a coherent and deliverable systems architecture. This will require MOD to prosecute a design authority role for the overarching C4ISTAR architecture which it shall own and over which it shall exercise governance. In this role MOD will employ the MOD Architecture Framework (MODAF) on which guidance has recently been published[2].

B3.4 An effective C4ISTAR capability also requires access to an industrial sector that can integrate state-of-the-art technology into in-service equipment. There is therefore a need for continuous enterprise-wide technology insertion, which confirms the need for the exploitation of open system architectures and an acquisition process that can accommodate spiral capability development.

C4ISTAR System-of-Systems Architecture

B3.5 The development of the overall C4ISTAR system-of-systems is at the heart of NEC and one of the highest priority areas to address is the system-of-systems architecture and its design.

B3.6 Since the C4ISTAR system-of-systems extends across so much of defence capability, is informed by and informs defence doctrine, and will guide requirement setting and acquisition decisions, it requires ownership and design authority which can only rest within MOD. The criticality of the capability provided by C4ISTAR coupled with the complexity and diversity of interactions to deliver it mandate that the architecture cannot contain any elements of chance and that it must be designed[3] and subject to a measure of governance. **Therefore, MOD shall own and shall be the Design Authority for the C4ISTAR architecture.**

B3.7 **The design of the C4ISTAR architecture will be carried out in consultation with UK industry[4].**

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[1] *Enabling Acquisition Change , T. McKane, June 2006, section 13.12, p. 44*

[2] *IA/03/12/01, Joint DPA/DLO Working Instruction: Implementing the MOD Architecture Framework, dated 6th July 06*

[3] *one of the main benefits of NEC is that it has the potential to support emergent behaviour. That is, users should be able to configure the C4ISTAR system-of-systems either to perform new tasks that were not envisaged at the time of the original design or to perform existing tasks in new ways. This must be accommodated within the C4ISTAR architecture.*

[4] *recognising the ownership of IPR within current systems, any design partnership will require industry to operate co-operatively, generating design concepts that are inclusive across the C4ISTAR system-of-systems whilst retaining competition for procurement of specific systems within the open framework of the co-operation.*

B3.8 Experimentation and modelling will be important components of the architectural design process. **Therefore, experimentation and modelling will be a high priority in the design of the C4ISTAR architecture**

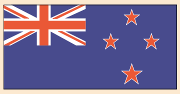
Maritime Net-Centric Warfare Experimentation

MAR TP-1: Command, Control & Information Management

Participants:


DSTO


DRDC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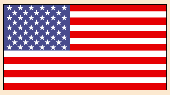

NUWC

Objective: Develop / demonstrate technologies for distributed coalition maritime Net-Centric Warfare command and control and information management

Programme: Virtual Battle Experiments (VBE)
Components: Synthetic environment; metrics for tactical picture, situation awareness; C2 applications development; engagement of military users

Payoff: Accelerated technological advance of tools and techniques to support distributed collaborative coalition net-centric maritime command & control and information management experimentation

B3.9 The sharing of data, information and intelligence across a network requires shared use of geospatial position and temporal frames of reference and shared use of agreed measurement metrics[5], as demonstrated through Project HINE[6]. Additionally it is necessary for all contributing sources to be capable of calibration by an agreed methodology using an agreed set of metrics[7]. Therefore, **MOD will participate, in collaboration with Allies and UK industry, in the adoption, and where appropriate development, of agreed geospatial position and temporal frames of reference, calibration procedures, measurement methodologies and metrics with which sources contributing data into the C4ISTAR system-of-systems will ultimately be mandated to comply.**

B3.10 It is recognised that such demanding standards have not previously been necessary across the wide range of defence activities covered by the C4ISTAR system-of-systems and the increased overhead which this imposes will be given very careful consideration as the architectural design develops.

B3.11 Networked assets open many possibilities for force operation that lie outside current doctrine. **Therefore the C4ISTAR architecture will be developed in partnership with all Defence Lines of Development, in particular Doctrine and Training**

C4ISTAR Technology Development

B3.12 For the purposes of this Strategy C4ISTAR technology is grouped under the four functional headings of:

- Command and Battlespace Management
- Collection
- Processing
- Communications and Information Systems

[5] for example, the Single Integrated Air Picture (SIAP) metrics of Completeness, Clarity, Continuity, Kinematic Accuracy, ID Completeness, ID Accuracy, ID Clarity and Commonality, with their associated technical definitions
[6] Project HINE is a research programme which showed, amongst other things, that different sensors looking at the same target in their own co-ordinate frames could produce very different estimates of the target s position and velocity when mapped onto the same reference frame
[7] this will also assist in the calibration of sensor performance models used in Operational Analysis/COEIA activities to support, for example, capability audits and EP submissions

B3.13 These are followed by the pan-C4ISTAR areas of Combat ID and Information Assurance and the C4ISTAR effector, Information Operations.

Command and Battlespace Management (CBM)

B3.14 The aim of CBM is to improve shared situational awareness (SSA) and the way we command and control in the Joint Interagency and Multinational (JIM) Battlespace.

B3.15 To realise the CBM mission, five critical building blocks have been identified[8]:

- Shared Situational Understanding
- The Right People
- Agile Groups
- Appropriate Connectivity
- Information and Intelligence

B3.16 Shared Situational Understanding is a human construct requiring technology to support the generation and exploitation of a common understanding of a situation and of future intentions.

B3.17 Development of the Right People recognises that in addition to technology advances in networks and information, the role of appropriately educated and trained people is critical to the delivery of capability.

B3.18 Agile groupings are critical to battle-winning tempo and MOD requires the ability to conduct the dynamic grouping and regrouping of widely distributed actors across joint, national, multi-national, military and non-military boundaries.

B3.19 The network is one of the three dimensions of NEC and as such Appropriate Connectivity underpins the whole of C4ISTAR.

B3.20 Accurate and timely information and intelligence are central to decision superiority. In particular MOD needs the ability to identify information needs and then to access, share and exploit both existing and new information, while assuring its provenance.

B3.21 The wide breadth of the CBM function is self evident and must be considered in conjunction with the following sections on Collection, Processing and CIS.

Table 1. Technologies Supporting the Command and Battlespace Management Function

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Shared Situational Understanding	· the development of common operational data sets/ operating pictures. · shared geospatial position/ temporal standards. · agreed methods of sensor calibration. · tools to assist human appreciation of situations. · development of methods/metrics to measure levels of situational awareness. · tools for collation/integration of diverse information sources (Red, White, Blue and Environmental pictures). · generation/visualisation/ maintenance of common data sets.	Algorithms to overcome the Gridlock problem in current and future UK assets and to ensure compatibility with coalition partners	Geospatial position and temporal standards; methods of sensor calibration, metrics and measurement techniques; common data sets
Campaign, Operation, Mission planning and Battlespace Management	· tools to assist selection of appropriate kinetic/non-kinetic effects to realise strategic aims. · tools to support course-of-action examination /selection. · tools to assist in translating desired effects into a plan of action, at multiple levels of command, across multiple agencies. · tools to support the execution of plans and the capability to support dynamic re-planning during a mission. · techniques to identify risk and uncertainty in plans. · tools to assist in the assessment of success in realising effects. · real-time asset management/co-ordination including visualisation of asset status, location and tasking.	Algorithms, processes and understanding of equipment interfaces	Implementation of algorithms

[8] *CBM Programme Update, endorsed by CBM Management Board on 23rd November 2004*

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Collection Co-ordination and Information Requirements Management (CCIRM)	· as above with the addition of: - tools to assist in translation of a desired effect into tasking of multiple assets. - tools to track Requests For Information (RFIs) from initiation to completion.	Algorithms, processes and understanding of equipment interfaces and capabilities	Implementation of algorithms
Human integration and interoperability	· development of the human/ cognitive dimension to the interpretation/exploitation of shared awareness. · human/technology integration – the role of the human as a sub-system.	Cognitive modelling	Understanding of human performance and behaviour
Collaborative working (distributed and co-located)	· tools to enable leadership in virtual environments. · synchronous information sharing technologies. · exploitation of COTS/MOTS products to specific military applications.	Exploitation of commercial products in military applications	Tools to enable leadership in virtual environments; synchronous information sharing technologies
Command and Control	· tools to implement adaptive command and control. · tools to assess and improve HQ effectiveness. · tools to maintain an audit trail on decision making.	Exploitation of commercial products in military applications	C2 tools

B3.22 MOD's technology priorities for the CBM area are therefore the development of algorithms and shared standards necessary to implement the CBM function[9], cognitive models for human integration, the exploitation of commercial products for military needs and a greater understanding of human capability in the CBM role. Ownership of the intellectual property behind algorithms may be sovereign[10], but implementation will generally be achieved through collaboration. Basic computing hardware and visualisation technologies will generally be sourced as commodity items.

Collection

B3.23 Collection is the gathering of data and information from real world sources and the delivery of that data for the production intelligence. Traditionally collection has focused on the use of ISTAR-specific military sensors but is increasingly exploiting wider military sensors, non-military sensors and agents, the operating environment, the cognitive domain and also social, economic and religious factors.

B3.24 To ensure value for money when procuring high performance military sensors it is necessary to be able to demonstrate that, when required, the UK could design, manufacture and integrate such sensors itself. Therefore, for those high performance military sensing technologies of importance to the MOD the UK should have an internationally recognised national capability in design, manufacture and integration up to TRL 6.

B3.25 It is recognised that modern design and manufacturing technologies using, for example, modular scalable multifunction components and sub-systems, allow for the re-use of basic designs in a number of different applications. This allows the maintenance of a TRL 6 capability at a more affordable level than that required by bespoke sensor designs.

B3.26 For the majority of sensor types, much basic hardware technology is common to many domains. In these cases, the common technologies are brought out in the Cross-Cutting Technologies Chapter, whilst this section highlights the C4ISTAR specific aspects of each technology.

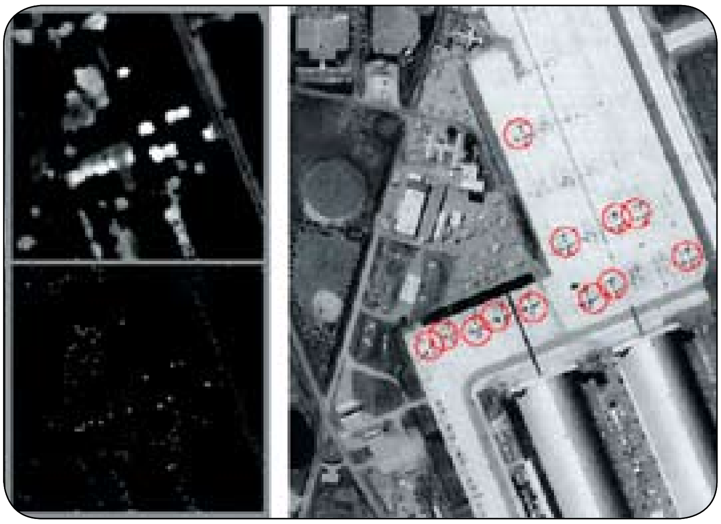
[9] *whilst recognising that the CBM function addresses all Defence Lines of Development*
[10] *except in cases where the UK makes direct use of another nations algorithms*

Table 2. Technologies Supporting the 'Collection' Function

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Sources			
Communications electronic surveillance	· detection of spread spectrum signals. · co-channel signal detection and copy. · prosecution of individual multiple access protocols. · single and multi-platform precision emitter geolocation.	Ability to demonstrate TRL 6 maturity	Optional route predicated on national capability at TRL 6
Radar electronic surveillance	· compact UAV payloads.	Ability to demonstrate TRL 6 maturity	Optional route predicated on national capability at TRL 6
Radar	· multi-perspective SAR image formation and registration. · low frequency ultra wide band SAR image formation. · ground moving target indication. · passive detection and geolocation techniques · multistatic operation.	Ability to demonstrate TRL 6 maturity	Optional route predicated on national capability at TRL 6
Passive electro-optic/ infra red	· see Cross-Cutting Technologies chapter.	See Cross-Cutting Technologies chapter	See Cross-Cutting Technologies chapter
Active electro-optic/infra red imaging (incl. LIDAR, BIL)	· 3D terrain model collection techniques. · 3D target geolocation.	None	3D terrain model collection techniques; 3D target geolocation
Multi-spectral and Hyper-spectral imaging	· optical design. · detector/filter cold shield. · smart focal plane processing.	None	Optical design; detector/filter cold shield; smart focal plane processing
Acoustic (under water)	· compact payloads for survey and reconnaissance.	Ability to demonstrate TRL 6 maturity	Optional route predicated on national capability at TRL 6
Acoustic (ground based)	· unattended ground sensors for vehicle monitoring and characterisation.	None	Unattended ground sensors
Cognitive	· understanding an opponent's interpretation of events and future intentions.	Understanding an opponent's interpretation of events and future intentions	None
Humint	· technologies to sense and predict human behaviour. · mental models.	Technologies to sense and predict human behaviour	Mental models
Cyber	· network mapping. · traffic and systems monitoring. · vulnerability analysis. · event analysis and integration. · data fusion.	Ability to demonstrate TRL 6 maturity when not available commercially; exploitation of commercial products in military applications	Case specific technologies
Environment (meteorological, oceanographic, hydrographic)	· optimising data collection from all operationally deployed meteorological, oceanographic and hydrographic sensors. · optimising EO/IR/SAR collection techniques to collect hydrographic, oceanographic and meteorological data.	None	Optimisation methods
Non-traditional sources	· integration of non-traditional sources into C4ISTAR infrastructure.	Integration of non-traditional sources into C4ISTAR infrastructure	Annotation of non-traditional sources with appropriate metadata
Open sources	· internet, television, radio, newspapers, specialist publications.	Integration of selected non-traditional sources into C4ISTAR infrastructure	Annotation of non-traditional sources with appropriate metadata

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Networked sensor control, management and cueing	· creation of ad-hoc sensor groups · understanding of existing sensor behaviour and required interfaces for integration. · data fusion technologies to manage large data volumes and feed back to control the sensor network.	Algorithms; understanding of equipment interfaces	Implementation of algorithms
Platforms			
Low cost unmanned platforms	· lightweight, long endurance power sources. · autonomous decision making for vehicle and mission control. · sense & avoid technologies. · autonomous data reduction. · platform performance in adverse conditions. · low mass, volume, power consumption sensors. · certification of unmanned platforms.	Autonomous decision making algorithms	Lightweight, long endurance power sources; implementation of autonomous decision making algorithms
High altitude platforms	· design and integration of platforms and payloads, command and control systems and ground stations.	None	Design and integration of platforms and payloads, C2I systems and ground stations
Adaptable UAVs	· system integration skills to realise adaptability to differing roles.	System integration skills	UAV platform and interface specifications
Small satellites	· design and integration of satellite and payloads, satellite command and control systems and satellite data reception.	Integration of satellite and payloads	Procurement of satellite bus and payload
High altitude platforms	· design and integration of platforms, payloads, command and control systems and ground stations.	None	Design and integration of platforms and payloads, command and control systems and ground stations
Platform supportability	· technologies necessary for the UK to hold in order to maintain platform availability now and in the future.	Platform specific	Platform specific

B3.27 Future trends in collection will be towards synchronised operation of multiple platforms and sensors that may be separated in space, time and collection mode. This requires the use of sophisticated control and management techniques to ensure that high-level command is correctly interpreted into individual collector commands and that the combined result from all collectors is processed and fed back in near real-time to update individual collector commands as a task progresses. Whilst such control and management techniques should begin to be developed in a simulated environment, it is recognised that demonstration of synchronised multiple collector operation in a representative real world environment is a necessary part of the development and proving process.



Target detection algorithm

B3.28 The need for a multi-collector demonstration environment is not unique to C4ISTAR operations, but occurs in other domains such as maritime and fixed wing, and is therefore covered in the Cross-Cutting Technologies Chapter.

B3.29 MOD's priorities for collection are therefore the development of a small number of high performance military-specific sensors at TRL 6, the ability to access and integrate selected non-traditional sources into the C4ISTAR framework and the demonstration of synchronised multiple collector operation in a representative real world environment.

Processing

B3.30 Processing is the conversion of raw data into intelligence through collation, fusion and interpretation. It is one of the most rapidly developing of all areas within C4ISTAR and is key to current and future defence capability. Traditionally this is an area where the UK has expertise and MOD intends to maintain this as a high priority area for the foreseeable future.

Table 3. Technologies Supporting the 'Processing' Function

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Data fusion	· data source characterisation. · error modelling & prediction. · the management of uncertainty. · multivariate statistical methods. · architectures and topologies to minimise data transmission.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms
Data mining	· assessment of patterns and relationships in data. · data visualisation. · ontology engineering. · text analysis/link analysis. · information retrieval. · multimedia information search and retrieval, automated annotation, segmentation and aggregation. · machine learning. · unstructured data searching. · modelling patterns and trends. · the management of uncertainty in searching.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms
Data reduction for bandwidth control	· intelligent stripping of high volume/low value content from data. · policy based prioritisation of message flow. · dynamic management of data transmission needs with available bandwidth.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms
3D target geolocation	· high grade inertial motion sensors. · improved integrated inertial navigation/GPS accuracy. · multi-image alignment. · simple and reliable automatic geolocation processes, especially registration with 3D digital terrain models.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms
Automatic target detection/ recognition	· target/ background phenomenology. · target/ background modelling and simulation. · sensor performance modelling. · feature extraction techniques. · methods of template derivation. · classification techniques. · seabed mapping from underwater sensors. · signal classification/ representation techniques for storage.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms
Positive identification	· classification techniques applied to high resolution optical and infra red imagery. · specific emitter identification.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms
Battle damage prediction/ collateral damage estimation	· techniques for the prediction of effects. · processing techniques for the assessment of effects. · methods to maintain auditable trails of decision making.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms
Image exploitation	· image registration and fusion. · wide area image screening. · image segmentation and terrain classification. · target detection and classification. · moving target detection and velocity estimation. · vehicle movement patterns. · change detection. · terrain elevation estimation. · image artefact removal. · automated feature identification and classification for map production. · extraction of hydrographic, oceanographic and meteorological information.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms
Translation and cultural awareness	· assisted translation. · methods to relate translation to known cultural background.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms
Non-traditional sources	· natural language processing techniques. · methods of filtering relevant data from non-traditional sources. · methods of fusing data from traditional/non-traditional sources.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment	Implementation of algorithms

B3.31 MOD's priorities for Processing are therefore to maintain a world leading national capability in algorithm design/ integration into systems, retaining the option for collaboration in the procurement of systems and assuming the provision of basic computing hardware as a commodity product.

Communications and Information Systems

B3.32 CIS technologies provide the infrastructure which underpins the whole C4ISTAR capability. This area in particular highlights some of the most difficult challenges within C4ISTAR: the management of large volumes of information across multiple, mobile agencies and security domains in strategic, operational and tactical environments over finite bandwidth links of varying robustness. Additional requirements such as guaranteed low latency (e.g. for air defence applications) provide further drivers which need to be reconciled with the developing system architecture.

B3.33 A range of technologies is required to realise MOD's vision of an end-to-end command and information system comprising:

- One general purpose backbone network based on Internet Protocol
- A single network security architecture
- A single family of joint CBM applications
- One managed, globally accessible information domain with:
    - controlled access to information in multiple security domains
    - one Joint Operational Picture
- An open, service oriented architecture with mandated standards
- Coherent joint and coalition interoperability

Table 4. Technologies Supporting Communications and Information Systems

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Bearers			
Satellite communications	· robust, secure telemetry, tracking and control. · dynamic bandwidth allocation. · high bandwidth optical (laser) links.	Robust, secure telemetry, tracking and control	Dynamic bandwidth allocation; high bandwidth optical (laser) links
HF, VHF & UHF communications	· software defined radio. · waveform design and integration. · self-organising nets. · IP over HF. · cognitive radio.	Waveform design and integration	Software defined radio; self-organising nets; IP over HF; cognitive radio
Broadband wireless networks	· interference suppression in dense wireless environments. · interoperability with existing networks.	None	Interference suppression in dense wireless environments; interoperability with existing networks
Tactical data links	· IP over TDL. · size, weight and volume reduction. · data looping. · multiple track management. · tactical beyond line of sight operation.	None	All
Underwater digital data communications	· underwater acoustic communications. · interference suppression. · underwater network integration across multiple platforms. · underwater modem design.	Underwater network design, manufacture and integration into the C4ISTAR architecture	Interoperability standards
Waveform design	· synchronisation schemes. · coding schemes. · modulation techniques. · access schemes. · smart spectrum usage. · low probability of intercept. · implementation of UK eyes only cryptographic techniques.	Implementation of UK eyes only cryptographic techniques	Synchronisation schemes; coding schemes; modulation techniques; access schemes; smart spectrum usage; low probability of intercept
Spectrum and bandwidth management	· cross layer technologies to enable effective bandwidth management. · Integrated spectrum management systems. · spectrum management tools.	Ability to integrate emerging techniques into capability	Ability to integrate information management with spectrum management
Distributed computing/ data distribution technologies	· low-cost wireless devices. · dynamic resource management including allocation of radio resources.	None	Commodity items

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Networks			
Network information distribution layer	· High Assurance Internet Protocol Encryption (HAIPE).	UK version of HAIPE	UK/US collaboration on HAIPE specifications
Mobile/ ad hoc/ dynamic networks	· auto-configuring. · self healing. · scalability for large numbers of users.	None	Auto-configuring; self healing; scalability for large numbers of users
Basic Infrastructure			
HQ IT (fixed and deployed, including dismounted)	· ruggedised PCs (including radiation hardening). · novel visualisation devices.	None	Commodity items
Operating Systems	· understanding OS design and operation to ensure MOD needs are met in future, publicly available releases. · test facilities.	Understanding OS design and operation; test facilities	Collaboration between MOD and supplier to ensure MOD needs are met without the need for bespoke MOD versions
Standard Applications	· email, web browsing, word processing, image visualisation and editing, collaborative tools (e.g. chat and whiteboards), VTC etc…	None	All commodity items
Information Assurance			
Cryptography (crypto design, implementation, management and support infrastructure)	· IP-cryptography (HAIPE). · Secure Communication Interoperability Protocol (SCIP). · link cryptography. · disk encryption. · software defined crypto. · programmable/flexible crypto. · software cryptographic systems and application cryptography. · key management. · chip design.	All	International specifications (e.g. UK/US collaboration on cryptographic specifications - HAIPIS, SCIP, LEFIS)
Computer Network Defence	· intrusion detection systems. · sensors. · intrusion protection. · event analysis and integration. · reaction and response. · virus, worm and malware protection. · security patch management. · denial of service prevention.	All	None
Secure Information Exchange Techniques (to support multi-level security)	· High assurance guards. · One-way diodes. · Message sanction and release techniques. · Digital Signatures. · Labelling and tagging.	Message sanction and release techniques, digital signatures	Guards, one-way diodes, labelling and tagging
Identity management/ access control	· Biometrics. · RF identification. · Public key infrastructure (PKI) credentials. · Smart cards.	None	Biometrics; RF ID, PKI credentials, smart cards
Information Management			
Information presentation	· extraction and presentation of contextually relevant information.	Exploitation of commercial products in military applications	Commodity items
Infrastructure to support Service Oriented Architectures	· web services. · enterprise service bus. · New Generation Operations Support System (NGOSS).	None	All commodity items
Knowledge stores and repositories	· information search, tagging and representation technologies. · high speed IO. · exploitation of COTS/MOTS products in military applications.	Exploitation of commercial products in military applications	Information search, tagging and representation technologies

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Information Management			
Information presentation	· extraction and presentation of contextually relevant information.	Exploitation of commercial products in military applications	Commodity items
Infrastructure to support Service Oriented Architectures	· web services. · enterprise service bus. · New Generation Operations Support System (NGOSS).	None	All commodity items
Knowledge stores and repositories	· information search, tagging and representation technologies. · high speed IO. · exploitation of COTS/MOTS products in military applications.	Exploitation of commercial products in military applications	Information search, tagging and representation technologies
End-to-end heterogeneous network management	· understanding the problem. · methods of managing commercial and military networks.	Methods of managing commercial and military networks	Understanding the problem
End-to-end data and information management	· content based data routing. · metadata structures and ontologies. · information search, browsing and auto-cataloguing. · information brokers, service brokers, database replication, caching and compression. · information access control. · mechanisms to achieve international interoperability. · methods of improving data quality and integrity across the enterprise.	All, except interoperability	Interoperability
End-to-end security management	· cross domain solutions. · secure gateways and guards. · authentication. · firewalls. · public key infrastructures. · secure use of insecure networks. · secure information sharing. · secure boundary controls. · multi-domain secure desktop working.	All	None

B3.34 MOD's priorities within CIS are therefore a sovereign capability in information management and assurance and in niche technologies applicable to certain bearers. Collaboration will be the general supply route with basic computing hardware assumed to be a commodity product.

Combat ID

B3.35 Effective Combat ID is the combination of situational awareness, target identification and tactics, techniques and procedures, used to increase operational effectiveness while reducing the incidence of casualties caused by friendly fire.

B3.36 This will be achieved by aligning research effort on Shared Situational Understanding and Target Identification whilst engaging with the User community to draw on, and influence, Tactics, Techniques and Procedures.

Information Assurance

B3.37 The UK has sovereign requirements to control all elements concerning cryptographic equipment to protect classified UK Eyes Only traffic. There is also a need to promote cryptographic interoperability with our Allies, especially the US and NATO, and nationally between MOD and Other Government Departments (OGDs).

B3.38 The UK strategy is therefore to adopt open standards for crypto interoperability, but to achieve UK sovereign protection MOD will negotiate the insertion of UK-national modes into the international interoperability specifications.

B3.39 A national UK capability will be supported by maintaining a UK industrial capability in research, development, design, manufacture, interoperability testing and support of cryptographic equipment built to international specifications and incorporating UK modes as required. The responsibility for national evaluation of UK-built cryptographic equipment against threat profiles will continue to be performed by the UK Government's Communications and Electronic Security Group (CESG).

B3.40 For Internet Protocol and Link cryptography the preferred interoperability specifications are the High Assurance Internet Protocol Interoperability Specification (HAIPIS) and the Link Encryptor Family Interoperability Specification

(LEFIS) respectively. These are US specifications into which UK requirements are being negotiated. For voice and data communications over fixed and mobile telephones and narrow band radios the NATO Secure Communication Interoperability Protocol (SCIP) is the preferred approach (based on the US FNBDT specifications). HAIPIS, LEFIS and SCIP are evolving and it is not yet known which versions of these specifications the UK will adopt. MOD is tracking these developments and will publish documents for UK industry specifying the "Minimum Essential Requirements" for national and international use, identifying which options in the specifications are required as a minimum for MOD needs.

B3.41 It is important to recognise that cryptography is one of several security components that are required for the protection of UK Eyes Only information and the delivery of networked capabilities. While cryptography retains separation between different classifications of data, other security components with equally high levels of assurance are required to support controlled information exchange between different security domains. These are a necessary underpinning to the concept of a Multi-Level Secure Global Information Infrastructure and support activities such as import of open source data into intelligence gathering and processing systems and output of downgraded intelligent product into command-control systems to support operational decision making. Examples of such technologies include High Assurance Guards, One-Way Diodes at network boundaries, desktop security components such as labelling and tagging systems and Smart Cards to perform the necessary digital signatures for approval and release.

Radio communications

B3.42 These technologies are available in the commercial market. However, two issues present significant obstacles to their use by MOD in an NEC context. Firstly, the levels of assurance they offer are generally insufficient to meet MOD's requirements for information exchange - particularly at the highest levels of classification. Secondly, they are generally developed and manufactured overseas, with little or no visibility of how and where critical components are developed and may present a weakness in the protection of UK Eyes Only information. These two factors together highlight a critical issue in delivering networked capabilities and will be addressed through the development of the information management architecture and the information assurance architecture within the overall C4ISTAR architecture

Information Operations

B3.43 Whilst the C4ISTAR domain is for the most part an enabling capability, it also includes responsibility for effects achieved through Information Operations (Info Ops).

B3.44 MOD requires a national capability to plan and execute Information Operations at Strategic, Operational and Tactical levels during exercises and operations. To support this capability MOD requires access to Info Ops planning tools and techniques applicable to effects-based operations, encompassing the planning of secondary and tertiary effects and the mitigation of unintended consequences. These tools and techniques concern the delivery of influence operations and counter command operations in the cognitive battlespace. The tools must be supported by Info Ops guidance in a form accessible to staff of disparate degrees of training and readiness and which can be used by all levels of military staff during the planning and conduct of exercises and operations.

B3.45 Many developments in Info Ops are driven by commercial interests and MOD will track these developments, along with those of our allies, in addition to maintaining a national capability in the planning and execution what will become an increasingly important military capability in asymmetric conflicts.

Integrated command systems © BAE Systems

Procurement Strategy for C4ISTAR Research and Development

B3.46 UK industry's C4ISTAR capabilities are broadly comparable with the rest of the world. To ensure continuing health it is necessary for UK industry to be active in the design, integration, maintenance, modification, assurance and support of C4ISTAR systems and in conducting and exploiting leading edge research in critical areas across the domain. Such an industrial capability can only exist if UK industry is routinely successful in winning orders and this will only be the case if high value for money solutions are routinely offered by UK industry into competed programmes. A co-ordinated technology development programme spanning MOD and UK industry is key to UK industry's ability to offer value for money solutions and therefore to retaining the capabilities specified in the DIS.

B3.47 Joint MOD – UK Industry analysis has shown that in most cases there are multiple companies with capabilities in the priority C4ISTAR technologies. Therefore the procurement strategy for future C4ISTAR research and development will normally be through competition.

B3.48 MOD recognises that many UK industries allocate significant proportions of their internal private venture funds to C4ISTAR-related technologies. Where appropriate MOD will align its investment to minimise duplication in these cases.

B3.49 MOD also recognises that the development of many C4ISTAR technologies can advance more rapidly and achieve a higher level of maturity with access to operational data sources. MOD will therefore work to widen the availability of operational C4ISTAR data sources to UK industry, subject to the application of specific restrictions appropriate to each source.

Way forward for C4ISTAR Technology Development

B3.50 The strategy for future C4ISTAR technology development is:

- MOD shall lead, in consultation with UK industry, the design of the C4ISTAR architecture.
- The C4ISTAR architecture will include an information management and information assurance architecture which will support interoperability nationally and with Allies.
- The C4ISTAR architecture will be developed in parallel with all Defence Lines of Development – especially the Doctrine and Training lines.
- MOD will participate, in collaboration with Allies and UK industry, in the adoption, and where appropriate development, of agreed geospatial position and temporal frames of reference, calibration procedures, measurement methodologies and metrics with which sources contributing data into the C4ISTAR system-of-systems will ultimately be mandated to comply.
- Experimentation and modelling will be given a high priority in the design of the C4ISTAR architecture.
- Within the limits of affordability MOD shall introduce a coherent, competed research and development programme aimed at delivering the national technology requirements identified in this chapter.
- MOD shall investigate with UK industry, the creation of a technically-focussed MOD-UK Industry C4ISTAR Development Group for joint discussion of research needs, research outputs, operational applications and perspectives and general topics of technical interest.
- MOD shall investigate, in collaboration with UK industry, the development of a joint MOD-UK Industry C4ISTAR technology roadmap to link research and development programmes across the MOD into programme decision points and intervention options for the delivery of the C4ISTAR system-of-systems, as part of a Through Life Capability Management approach[11] to acquisition.

[11] *Enabling Acquisition Change , T. McKane, June 2006, section 13.12, p. 44*

B4 Close Combat and Combat Support

Introduction

B4.1 The Close Combat Sector covers technologies for armoured fighting vehicles (Mounted Close Combat) and fighting soldiers (Dismounted Close Combat), as well as combat and land systems support.

B4.2 The Strategic Overview of the DIS Chapter on Armoured Fighting Vehicles (AFVs) describes the context for close combat operations. These objectives are carried through to this chapter and represent the required capability to be provided by the collective land force.

B4.3 The required capability is not fulfilled by the provision of equipment alone, but by the mix of the right equipment, effective use of Tactics, Techniques and Procedures (TTPs) and a balanced response in all situations. MOD's research programme aids the development of all these areas. However, the maturation of technology is a major part of MOD's research and development, and requires the involvement of industry in system integration and to ensure that equipment can be effectively designed and manufactured.

Royal Marines Commando in front of a Challenger 2 main battle tank, Iraq

B4.4 Considerable emphasis has been placed on reducing the initial procurement cost of equipment, but significant improvements can also be made to reduce costs in later years by designing future equipments to facilitate technology insertion. The early involvement of industry should optimise the time to bring new capabilities into service, technology insertion programmes and involvement in all through-life aspects to equipment disposal.

B4.5 This chapter addresses the breadth of the anticipated equipment, the techniques employed and resources required at a strategic level to ensure the UK retains its position as an effective fighting force. In the three capability areas a summary table gives details of the priority technologies and the areas where there is a need to retain national control; specific action points for each area are addressed in the sub-sections that follow the tables.

Priority Technologies for Close Combat

Table 1. Summary of Priority Technologies for Close Combat

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Platform Systems (Mounted)	Battlespace Management Systems inc: Software, Systems Design, Systems integration, physical architecture (inc. tech insertion), battlefield/climatic environments.	Maintain position as design authority to ensure TLCM (linked to AFV Partnering Agreement).	
	Electronics architecture Vetronics - Architectures Software/ Firmware/ Middleware/Hardware, safety and mission critical aspects crew station and fightability enablers Platform C4I – Communications, command & control, battlefield management system, crypto, control and interface to unmanned assets HUMS and asset management EMP/EMC	Design and integration of electronics architecture; mission critical systems, assurance of embedded software and firmware. Integration of survivability technologies	Research of new systems architectures Research related to interoperability in a coalition context
	Survivability system integration – e.g. electric-armour, electronic counter-measures and DAS	Overall system design and integration	

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Soldiers Systems Platform Integration	Physical Architectures - survivability Systems - lethality Systems - mobility - battlefield / climatic environments	Overall system design and integration Maintain assured access to physical design authority data and skills for TLCM. Integration of survivability technologies	Research of new systems architectures
	Electronic Architectures - Platform C4I / Sensors - Safety and mission critical software - Power	Design and integration of electronics architecture inc. mission critical systems, assurance of embedded software.	Research related to interoperability in a coalition context
	Human Architectures / Systems -Human Machine Interface (HMI) – HFI / Fightability -Asset management	Specification, prototype design, integration and test/assessment.	Research of technology to improve asset management
Lethality	Weapon systems - large & medium calibre guns/ cannons/ mortars, rockets - personal weapons technology - effect weapons (anti-materiel, anti-armour, anti-personnel) - close quarter combat systems - man-portable and vehicle mounted guided weapons - fire control (see General Munitions and Complex Weapons chapters for details)	Intelligent customer understanding, specification, integration and test/assessment. (Additional requirements for specific systems/ subsystems detailed in General Munitions and Complex Weapons chapters.)	Maintain intelligent customer understanding
	Ammunition natures (see General Munitions chapter)		
Sustainability	Power Sources - portable power supply and management, - generators - batteries - pulse power - alternative / novel power generation	Intelligent customer understanding, specification, integration and test/assessment.	Studies of new concepts for defence specific portable power Maintain intelligent customer understanding
	Power Management - Intelligent power management systems - power management systems for sensors, displays communications, and environmental systems, etc.	Intelligent customer understanding, specification, integration and test/assessment.	Research of technology to improve asset management
	Auto Re-supply through asset management		
Mobility	Electric-drive Power train Suspension Drive components Load carriage	Intelligent customer understanding, specification, integration and test/assessment.	Maintain intelligent customer understanding
Survivability	Armour Active protection, e.g. electronic countermeasures (ECM) Personal protection (battlefield and environmental) Materials technology (inc textiles) EO protection measures (EOPM), EOCM, Obscuration/ illumination, Signature management, CBRN Integration (see CBRN chapter for detail) Regenerative NBC protection (see CBRN chapter for detail), SA Combat ID	Design authority for Armour and CBRN integration. Design capability for EOPM, EOCM and ECM. Specification, prototype design, integration and test/assessment Ability to quicly and effectively re-programme survivabilty systems	Research of new survivability concepts
Structures	- novel and complex materials and concepts - systems integration	Specification, prototype design, integration and test/assessment. (See Cross-Cutting Technologies chapter for materials.)	Maintain intelligent customer understanding
C4I / Sensors infrastructure	C4I/ Infrastructure - Communication and networks - Cooperative engagement - Geo-location - Data fusion - Integrated image handling (See also C4ISTAR chapter)	Specification, prototype design, integration and test/assessment.	
	Sensors - EO - radar - acoustics - automatic target detection and recognition (ATD and ATR) (See also C4ISTAR & Cross-Cutting chapters)	Design, develop and prototyping capability.	

Platform and Soldier Systems

B4.6 The DIS has already established the MOD/BAE Systems Land Systems partnering and business transformation agreement. Under this arrangement BAE Systems Land Systems will act as systems integrator, both to deliver availability and upgrades through life for the current fleet, and to bring advanced land systems technologies, skills and processes into the UK.

B4.7 In order that our vehicle platforms achieve future requirements in weight, volume, cost whilst being capable of effective technology insertion, we will need to exploit developments in vetronics, electric drive, communications, sensors, displays, control functions and survivability systems. All are dependent on electrical power and employ to an increasing extent software, firmware and middleware (SW, FW and MW) processes, operating in increasingly complex hardware (HW) environments. Open architectures and modularisation of systems will lead developments into a 'black-box' possibly 'consumable' culture. An important component of Platform Systems is the Battle Management System. Specifically, the associated software and system integration are strategic capabilities that must be retained in the UK for through life maintenance.

B4.8 **Components and sub-systems may be procured off-shore but the system design must be retained in the UK. It is also important that the UK retains and develops a capability to understand in depth, the operational functionality of these systems.**

B4.9 This cannot be achieved simply through overseeing developments; it requires detailed analysis and testing in a compliance regime. MOD must have sufficient confidence that we can access the IP, design authority and capability to upgrade the fleet as required. This is realised through the early involvement of industry in the research programme, and links to the Partnering Agreement.

B4.10 Autonomous systems will be considered for non-weapons platforms such as ammunition handling and road trains but, due to the complex nature of operations and the environment, are unlikely to be taken forward in the near future for weapons based platforms.

B4.11 For the dismounted soldier the situation may appear simpler, but the issues of compliance and robustness are the same, and key to programmes such as FIST.

B4.12 It is strategically important to be able to assure soldiers that the equipment they depend on will always be available. For this reason, the UK supply base must retain and develop further its in-depth knowledge of the dismounted soldier communication and network systems.

Power Sources

B4.13 The availability of electrical power is a key issue for mounted and dismounted forces, in particular the provision of portable power for soldier technologies.

B4.14 Portable power can be provided either via generator packs or through battery systems. The major problem is in the area of batteries. Primary batteries are used extensively and power demands will increase, despite the availability of more energy efficient systems. Civil systems are being developed that significantly improve the power density of primary and secondary power sources. However, the operational needs in the civil environment are very different to the robust and demanding requirements of military platforms (e.g. high mass military vehicles with high rates of acceleration, deceleration, braking and turning over rough terrain). Although much can be exploited from civil products, bespoke military systems will therefore be required.

B4.15 Some early research has been conducted into fuel cells, but in general these have not delivered the earlier optimistic claims. **The development of low weight, conformable, high energy density and low cost portable power systems suitable for the mounted and dismounted soldier environments requires significant investment.** Exploitation of civil products can provide a starting point, but advances in technology will be needed in the context of military requirements, and this will be the focus of the MOD research programme.

Power Management

B4.16 Future AFVs are likely to have more electrical systems (e.g. electric drive, electric armour, air-conditioning, defensive aid systems (DAS), active signature control), all of which require power and generate heat. Power and heat management is therefore a subject of increasing importance and needs to be addressed. The civil market has made significant advances here. **Industry needs to incorporate these into military vehicle programmes.**

Elee (Copyright QinetiQ)

B4.17 Power management for the dismounted soldier is also an area of increasing importance. The proliferation of electronics (e.g. personal radios, navigation systems) adds a significant burden in weight, bulk and power on the individual. Power requires careful management through the use of efficient sources and/or low consumption loads. Again, the civil markets are likely to provide technological developments, and will need further development for military use.

B4.18 The growth of electrical systems in use will require strict conformance under the heading of Electro-Magnetic Compatibility (EMC). Despite the formal processes attached to conformance testing for EMC it is underpinned by years of experience in experts working in a few establishments in industry. EMC cannot be left to assurances provided at the time of original equipment procurement and the tendency towards open architectures is going to compound the problem. MOD must maintain access to these experts ensuring they are kept up to date on developments and the impact they will have on EMC. This is an important systems design issue, and there is a role for both industry and MOD, in order to maintain expertise in the UK.

Personal radio

Survivability

B4.19 With an emphasis on weight and volume reduction, the survivability of vehicle platforms will be dependent in the future on the development of collective systems that together provide the required level of protection.

Armour

B4.20 To retain a world class capability in armour systems requires a broad base of research: understanding the threat, the weapons their performance and use, the vulnerability of vehicle and man. Modelling has increased the understanding, and to a limited extent the predictability, of interactions and structures, but the development of armour systems continues to be heavily dependent on empirical techniques and trials. **Given the sensitivities associated with armour the Design Authority has remained within MOD. This must continue but with an increasing need to transfer solutions and expert guidance, generated through MOD research, to UK Industry as the manufacturers of AFVs and body armour.** The current approach to this is to ensure that the relevant Tier 2 industries are involved in the latter stages of research programmes to enable the pull through of technology and expertise.

B4.21 The world demand for many of the key materials used in armour and structures is greater than that readily available on the open market. This is causing severe problems in the procurement of high quality steels, high hardness aluminium, copper, non-oxide ceramics and the more exotic materials such as titanium, molybdenum, vanadium, nickel and chromium. **Developing or maintaining a UK based supply for all of these materials is unrealistic, but we judge that this will be necessary for non-oxide ceramics. MOD will invest in research to enable material requirements to be specified, and will work in partnership with UK industry to establish a route to a material production capability.**

B4.22 Personnel protection against blast, heat, fragment and bullet attack has been undergoing a process of continuous development. Although current body armour is effective against the penetration of high velocity rounds, the effects of behind armour blunt trauma (BABT) can be very serious. **Research is therefore required to develop lighter-weight, lower-volume armours that also reduce BABT.** Improved head ballistic protection is also required.

Defensive Aid Systems

B4.23 Defensive aids are expected to be a major component of an integrated survivability capability. Sensors are used to detect either high velocity incoming rounds or emissions from weapon guidance/seeker systems, and cue the relevant action needed to neutralise the inbound threat. Sensor technology operating in the bands of interest is a current strength within UK Industry, but could be jeopardised if there is insufficient take-up in procurement programmes. **UK industrial capability in defeating close-in weapons is limited but the technology can be sourced offshore. Where this is the case, UK integrators must have access to the design, implementation and mission-critical details, and the appropriate expertise and tools (e.g. threat analysis software) must be maintained, to integrate and adapt these into our systems.**

Structural Design

B4.24 Traditionally, the vehicle structure has formed the basis of the armour protection, but it is now likely to be a more complex, fully integrated system that contributes to an optimised, coherent solution for survivability. European legislation requirements will have to be met in future systems, therefore MOD needs to address vibration and other environmental issues.

B4.25 In addition, an understanding of signature management technology and techniques and the relationship with platform design must be maintained.

B4.26 To achieve the requirements of survivability against an evolving threat and the constraints of weight, volume and power, radical departures from conventional AFV structures and designs will be required in systems from 2025 onwards. **In order to deliver such highly optimised solutions, the Design Authority will remain in UK industry. Innovative approaches to systems design will be a priority in the MOD research programme, but it is important to engage the industry primes in this work at the earliest opportunity.**

Optical Systems

B4.27 Thermal imaging (TI) systems have been the mainstay of our night-fighting capability and will continue to be so. The capability required falls into two categories; high performance TI for long-range (up to 4km) surveillance, target detection, identification and tracking, and lower performance TI suitable for dismounted forces. In the latter case, low weight, volume and cost have driven un-cooled TI technology and in the long term, un-cooled technologies will probably deliver this. The need for Electro-Optic Protective Measures (EOPM) is based on the potential threat from laser based weapons and systems. In line with sensor systems development, the UK has a world-class capability in EOPM.

Priority Technologies for combat support

Table 2. Priority Technologies for Combat Support

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Counter-mine Systems	Sensors including - Forward Looking Ground Penetrating Radar - Downward Looking Ground Penetrating Radar - Ultra-Wide Band radar - Metal Detection - EO - Hyper-Spectral Imaging - Nuclear Quadrupole Resonance - Data Fusion and Human Interface.	Specification, prototype design, integration and test/assessment of sensors	Research of new countermine techniques and concepts
	Neutralisation of mines and/or explosive ordnance; both making safe individual devices and breaching minefields: - Mechanical systems: ploughs and flails - Explosive Systems - Electro-Magnetic Systems	Intelligent customer understanding, specification, integration and test/assessment	Seek collaboration on innovative programmes
Gap-Crossing Systems	Strong, lightweight and rapidly deployable. Lightweight structural materials Design and assessment techniques	Specification, prototype design, integration and test/assessment.	
Counter-mobility Systems	Low-cost unattended ground sensors: - Acoustic - Seismic - Magnetic - EO - Milli-metre Waves (active and/or passive) Alternatives to batteries as power sources Secure and robust Networks	Specification, prototype design, integration and test/assessment.	Research of new counter-mobility techniques and concepts
	Remotely controlled lethal effects : Technologies addressed under General Munitions and Complex Weapons chapters		
Force Protection Engineering (FPE)	Software and predictive models, underpinned by a library or material properties, for planning and assessing threat mitigation measures. Specific technologies (such as remote sensing, human behavioural analysis, remotely operated less-than-lethal barriers/arrestors and re-enforced composite protective structures).	UK MOD to be authority for FPE operational advice.	Studies of new techniques and concepts

Countermine

B4.28 Anti-tank and anti-personnel mines continue to be a significant threat to UK operations. Currently, breaching systems are well researched and available as MOTS equipment, however countermine systems suitable for Reconnaissance (Recce) and MSR clearance are some considerable way from being able to deliver the required performance. Many technologies (e.g. Ground Penetrating Radar, Electro-Optic, Nuclear Quadrupole Resonance) have been investigated, but are currently unable to detect buried or off-route mines at the required rate or level of certainty. A systems approach needs to be investigated based around information fusion for detection, marking and neutralisation of the above threats. **This is an area requiring substantial research investment. An increased emphasis will be placed on engaging the widest possible range of expertise and innovation, seeking collaborative programmes as appropriate, to identify technology that could provide a step change in mine countermeasures.**

Mine detection

Counter-mobility

B4.29 Affordable large area denial disruption, turning or blocking an adversary provides a major defence challenge given the limitations on autonomous systems, requiring a technical breakthrough to provide an acceptable level of capability. **Research will be focussed on innovative solutions to low cost, large area denial capability that previously would have been provided by mine deployment.**

Gap Crossing

B4.30 The UK has a uniquely valuable capability in gap crossing and bridging systems will remain an essential component of fighting capability. Major investment in technology development is not required, but there is a demand for novel lightweight materials formed into quickly erectable bridging systems capable of bearing high and concentrated loads. **In order to further develop the capability and to sustain the UK industrial base, an innovative research programme will be needed together with exploitation into procurement of advanced crossing systems.**

Force Protection Engineering

B4.31 Recent OA and experience from current operations have confirmed the need for an enduring capability to protect own forces and assets from attack when static. Force Protection Engineering (FPE) addresses this through a diverse range of measures (e.g. hardened structures to enhance the protection of camps, system to provide early warning of in-coming weapon attacks, protection against personnel and vehicle-borne suicide bombers). **Substantial investment is needed to enable research to maintain this capability and provide the necessary rapid response to these challenges.**

Priority Technologies for Land Systems

Table 3. Summary of Priority Technologies for Land Systems

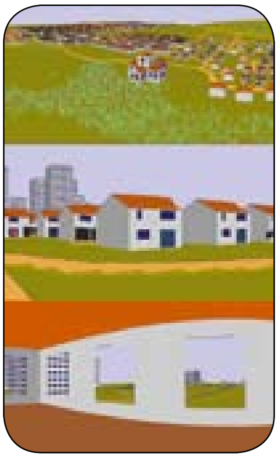
Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Logistic Support	- B-Vehicles - Power Generation - Accommodation - Water - Fuel - Waste Disposal - Autonomous systems - Ammunition handling - Road trains	Specification, integration and test/assessment	Intelligent customer understanding
Training	- Embedded - Collective	Specification, integration and test/assessment	Intelligent customer understanding

Logistic Support

B4.32 The technical solutions to many of these platforms and systems have to be re-defined in the context of Expeditionary Support and Rapid Reaction. However, the technologies employed can be procured as commodities. The primary effort therefore is to maintain a technology watch of developments to ensure the most appropriate solutions are identified and procured.

Training

B4.33 Advances in communications, displays, information handling and synthetic representations are being investigated in the research programme for provision of mission planning, preparation and embedded training facilities. The research programme will continue to investigate how operational effectiveness can be enhanced through the use of emerging technologies, with the emphasis on technology watch and some targeted technology development.



The 'Close Action Environment' wargaming and simulation tool

Way Forward for Close Combat and Combat Support Technology

B4.34 In summary the key issues for technology are:

- MOD will continue to maintain key system design expertise and design authority in UK industry, including integrated system design, through life management, power management and EMC.
- MOD must develop and implement new technologies on platform and soldier protection including countermine. We will therefore seek innovative technology solutions in this area from academia and industry.
- MOD must adapt emerging civilian technology on power storage.
- MOD will maintain access to key structural materials in particular non-oxide ceramics for use in armour systems.
- MOD must have access to the design, implementation and mission-critical details of DAS and the appropriate expertise and tools required.

B5 CBRN

Introduction

B5.1 Current UK defence policy is committed to maintaining the UK's political and military freedom of action despite the presence, threat or use of Chemical, Biological, Radiological or Nuclear (CBRN) weapons[1]. This policy draws on the four well-established, inter-related areas of Arms Control, Preventing Supply, Deterring Use and Defending Against Use and is extending to include the two new areas of "Disablement" and "Elimination". Action is also in hand to better define the changing nature of the threat[2] to inform the development of policy and capability, based on the assessment of risk.

B5.2 The MOD's approach to tackling CBRN will be a continuum of activities which reflect the fact that no single solution can adequately address the risks posed by CBRN.

B5.3 Our defensive capabilities have been defined in the DIS and are broken down into:

- **Timely Warning –** the detection and identification of CBRN weapons and materials, with the ability to process data and provide information to facilitate decision-taking and action;
- **Survive –** the capabilities, based around the person, necessary to survive a CBRN challenge;
- **Sustain –** the unit/force level capabilities required to confirm the extent of a hazard, rapidly recover from an event, and sustain/regain operational tempo.

B5.4 These capabilities are brought together by taking a systems approach to CBRN defence. The capabilities and their component technologies comprise a complex and interlinked system supported by a combination of equipment lines and technological developments that impact across all the lines of development.

B5.5 In addition to delivering the capability needs, CBRN technology investment also has a key role to play in the maintenance of the strategic UK capability which resides at Dstl Porton Down. Many other Government departments and MOD Special Forces are also dependent on high quality CBRN advice, assistance and facilities, often at very short notice, which are available as a result of the MOD research programme. Furthermore, the access to facilities and expertise required for handling highly toxic materials is becoming an increasing requirement for industry and academia.

Microbiological Containment Facility at Dstl

B5.6 CBRN has traditionally been regarded as a domain of "in-Government" research. Nevertheless, over the last 10 years there has been a significant expansion of the "non-Government" capability in CBRN and Dstl plays a vital role in capturing and integrating 'external' technological advancements relevant to MOD CBRN defence. However, to enable the capability requirements to be met, there is an increasing need to achieve better exploitation of technology developments from all potential suppliers of technology.

Priority Technology Areas

B5.7 There are a number of inter-linked key functions and technology areas that underpin the strategic requirements. The following diagram shows the relationship between the functions and desired military capability. The summary table gives details of the priority technologies and the areas where there is a need to retain national control; specific action points for each area are addressed in the sub-sections that follow the table.

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[1] *Delivering Security in a Changing World White Paper; Provisional Defence Planning Assumptions 2005*
[2] *MOD WMD Task Force Threat Panel*

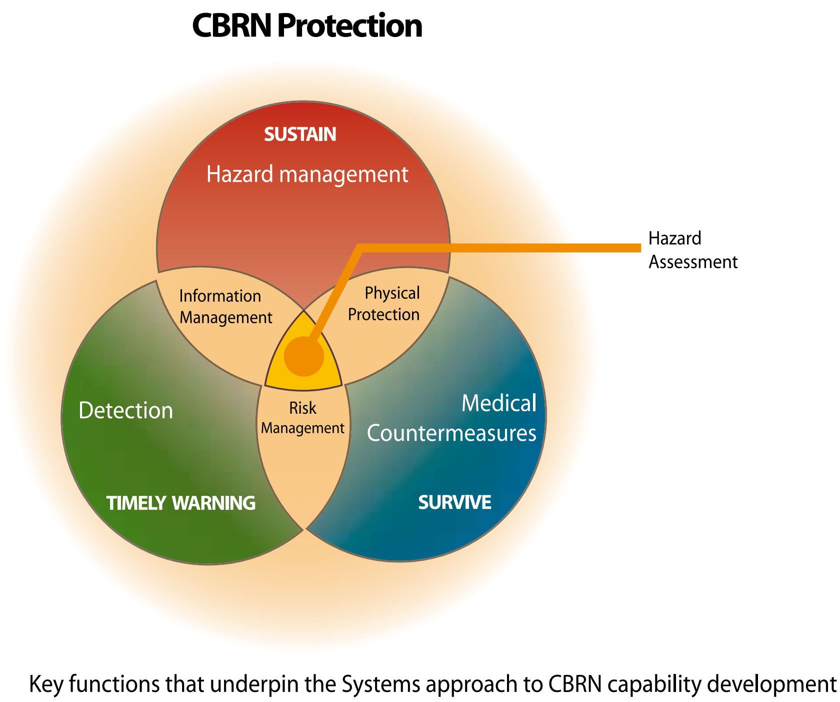


Figure 1. CBRN Protection

Table 1. Summary of Priority Technologies

Function	Priority Technology Areas	National Capability Requirement	Potentially through collaboration
Hazard Assessment	CBRN agent characterization and analysis	Ability to synthesize, characterize and handle super toxic compounds Design and development of methods and technologies for the identification of CBRN materials in biological and environmental samples	Understanding the persistence of CBRN agents in a range of environments
	Biotechnology and toxicology	Evaluation of super-toxic chemical and biological materials (micro-organisms, toxins and chemicals of biological origin) in appropriate models Ability to handle dangerous (Category 3 & 4) pathogens Ability to understand the potential hazard emerging from developments in biotechnology (e.g. genetic engineering, bioactive peptides etc) Access to secure supply of experimental animals (including non-human primates)[3] Identification and development of alternatives to animal testing Investigation and development of techniques for refining animal experiments	
	Information integration	Ability to integrate knowledge of the CBRN hazard with intelligence information	

[3] MOD uses animals for defence research to develop protective measures and procedures to safeguard UK service personnel against battlefield and other hazards. It does not use animals to develop weapons or offensive capabilities. MOD is fully accountable, as are all other UK institutions employing animals in scientific research, under the Animals (Scientific Procedures) Act 1986. This is legislation is enforced by the Home Office, through their inspectorate.

Function	Priority Technology Areas	National Capability Requirement	Potentially through collaboration
Detection and Identification of CBRN Agents	Sampling and collection technologies	Design and development of methods and technologies for collecting CBRN agents from the air and off surfaces (e.g. inlets, filters, cyclones, electrostatic collectors, surface sampling techniques etc)	Sub system technologies and underpinning science
	Sample processing	Design and development of automated technologies for rapid processing of samples (including microfluidics)	
	Sensors and sensing elements	Design and development of sensitive sensor technologies for the rapid detection and identification of chemical and biological agents including 'stand off' technologies that work at a distance from the agent source (optical biosensors, PCR, IMS, HiFAWS, LIDAR, hyperspectral imaging etc) Limited need for design and development of further radiological sensors	Sub system technologies and underpinning science. Joint field trials to evaluate potential technologies
	Biotechnology	Ability to develop and manufacture bio-consumables (e.g. antibodies) for incorporation into sensors and detection systems	
	Detection systems integration	Ability to integrate collection, processing and sensor technologies to produce CBRN detection and identification systems that provide information in an appropriate format	Sub system technologies and software.
	Diagnosis	Design and development of technologies for the rapid diagnosis of infection (e.g. PCR, microarrays etc)	Sub system technologies and underpinning science.
Information Management	Networked sensor management	Development of algorithms and data fusion techniques for collection and integration of data from CBRN sensors and detection systems	
	Dispersion modelling	Development of algorithms, source terms etc to allow accurate modelling and prediction of CBRN agent dispersion	Understanding the dispersal of airborne CBRN agents and their movement under different meteorological conditions in all environments
	Warning and reporting tools	Design and development of information tools and decision aids that are compatible with sensors, sensor management tools and non-CBRN information systems (see C4ISTAR and Cross-Cutting Technologies chapter)	Development and evaluation of command and decision tools (e.g. NBC BISA) and sensor management systems (e.g. ISMS)
	Synthetic environment	Design and development of a CBRN synthetic environment (CBRN 'virtual battlespace') to enable OA and research ideas to be validated experimentally, equipment programmes to be de-risked and appropriate training to be developed	Underpinning software and architecture.
Physical Protection	Materials science	Design, development and manufacture of CBRN-resistant materials for incorporation into clothing and collective protection systems Understanding and development of materials which adsorb chemical agents for incorporation into filtration and CBRN protection systems	Sub system technologies and underpinning science. Joint field trials to evaluate potential technologies
	Physiology	Understanding the physiological burden imposed by individual protective equipment (respirator, clothing, gloves, overboots etc) Design, development and manufacture of protective systems that provide a balance between CBRN protection and physiological and logistic burden	
	Filtration technologies	Design and development of low burden (logistical and/or physiological) filtration systems (e.g. regenerative systems)	

Function	Priority Technology Areas	National Capability Requirement	Potentially through collaboration
Medical Counter-measures	Pharmacology, immunology, microbiology, pathology, veterinary science	Understanding of how CBRN agents act upon the body to produce their effects, to allow rational development of medical countermeasures Identification, development and licensing of medical products (e.g. vaccines, antibiotics, chemical agent therapies etc) including efficacy testing in a range of in vitro and in vivo models Ability to handle dangerous (Category 3 & 4) pathogens and super-toxic chemicals in order to test the efficacy of medical countermeasures against realistic CBRN agent challenges Access to secure supply of experimental animals (including non-human primates) Identification and development of alternatives to animal testing Investigation and development of techniques for refining animal experiments	Joint trials to evaluate potential candidate medical countermeasures and technologies and develop through to licensed medical products
	Clinical Science[4]	Ability to conduct experiments and clinical trials in human volunteer subjects for licensing of medical products to meet UK and EU legislation	
	Biotechnology	Application of genetic and protein engineering techniques to the identification and development of medical countermeasures (including vaccines and generic post-exposure therapies) Limited need for design and development of drug delivery methods and technologies	
Hazard Management	CBRN monitoring	Design and development of technologies for the rapid detection and identification of CB agent contamination on surfaces (personnel, equipment, platforms and terrain), including 'stand off' technologies that work at a distance from the agent source Very limited need for further development of radiological monitoring capability	Sub system technologies and underpinning science. Joint field trials to evaluate potential technologies.
	Materials science	Design, development and manufacture of methods and technologies that enable thorough CBRN decontamination of platforms, personnel, terrain and equipment (including sensitive equipment and platforms e.g. airframes) Design and development of materials that indicate areas of contamination ('disclosure')	Sub system technologies and underpinning science. Joint field trials to evaluate potential technologies.
Test and Evaluation	CBRN agent trials	Ability to evaluate technologies under realistic conditions Agent challenges (e.g. live biological agents), not simulants Field conditions rather than 'ideal' laboratory environments	Collaboration with allies to access facilities
	Equipment standards	Understanding minimum exposure levels for CBRN agents in order to set appropriate equipment standards and to enable informed risk management	Common approach to equipment evaluation and assurance; development of common standards

Hazard Assessment

B5.8 The objective of hazard assessment is to maintain the ability to provide an effective assessment of the current and developing CBRN hazard. This is the bedrock on which sound CBRN defence is built. The information generated helps define defence strategy, concepts and doctrine, as well as identifying the required performance of protective equipment. **For security reasons, the capability to perform hazard assessment lies within Government and will do so for the foreseeable future.** This capability within Dstl is recognised as world leading and is maintained through a combination of targeted studies and utilisation of the expertise developed as part of the core research programme.

B5.9 An important short term objective in this area is to develop a capability to address the full range of defence issues associated with the most dangerous pathogens. The recently acquired capability to handle category 4 pathogens and the maintenance of animal breeding facilities at Dstl Porton Down are key components of this technology area. **Whilst hazard assessment at present relies on data derived from animal experiments, MOD will actively pursue reduction, refinement and replacement of animal experimentation, exploiting new developments in academia and industry.**

Dstl containment facility used to evaluate new medical countermeasures

[4] *Research involving human participants undertaken, funded or sponsored by MOD must have appropriate ethical clearances and meet acceptable ethical standards. Ethical standards are upheld by the MOD Research Ethics Committee.*

B5.10 The output from the hazard assessment programme is integrated with information regarding the threat that is derived directly from intelligence information. **Security considerations permitting, MOD will make every effort to release limited hazard assessment information to strategic industrial partners (identified through implementation of the CBRN elements of DIS).**

Detection of CBRN Agents

B5.11 Our aim is to continue to investigate the rapid detection and identification of CBRN agents, with the ultimate goal of a generic capability to detect all agents in time to protect those at risk. Our capability to detect chemical agents and radiological hazards has significantly improved recently with the introduction of the Lightweight Chemical Agent Detector (LCAD), man-portable chemical agent detectors and Tactical Radiation Monitoring Equipment (TraME). Whilst we will rely on civil supply in the area of radiological detection, MOD will continue with limited research investment in chemical detection technologies to further develop the sensitivity, specificity and range of chemical detector systems. **In the medium term (10-15 yrs) the highest priority will remain with the detection and identification of biological agents, supported through the MOD research programme.**

B5.12 A number of current MOD bio-detection systems are based on specific biological recognition elements (antibodies, gene probes etc). Security issues are of vital importance to ensure that UK retains sovereign control of production of such recognition elements. **There is a limited UK supplier base for the capability to produce CBRN bioconsumables and development of an improved industrial capability will be supported through an MOD-funded TDP programme starting in 2007.** We judge that the biggest gains in sensitivity and rapidity of detection will come from more effective collection and sampling technologies, coupled with improved sample processing technologies. In addition, priority for future research will be detector technologies that do not rely on expensive, labile recognition elements, in an effort to drive down through-life costs. Whilst there is a healthy UK and worldwide capability for detection technologies, the UK needs to maintain a critical mass of design and systems integration expertise on-shore to allow it to act independently. **MOD will collaborate with academia and industry to develop smaller (man-portable) biological detection and identification systems and support TDPs to de-risk potential capability solutions.**

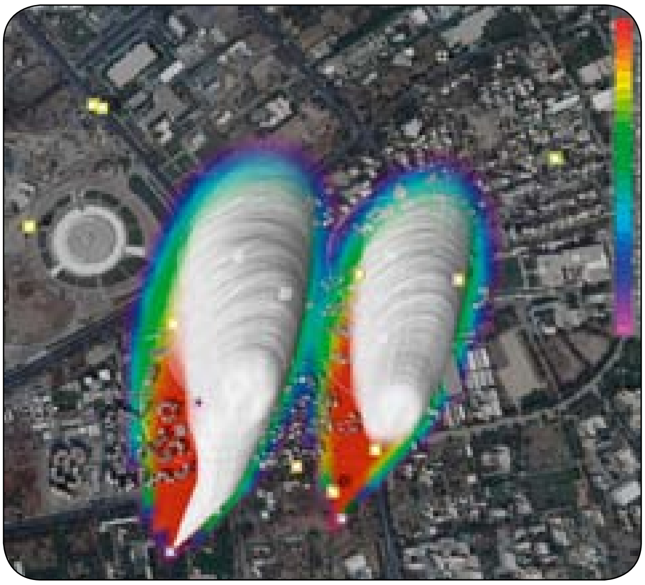
B5.13 The ability to understand the effects of biological agents upon the body and develop methods and technologies that allow early identification of infected personnel (ideally before symptoms develop) is a vital component of the Timely Warning capability. **Detection of infection methods and technologies will be addressed through collaborative research programmes with academia, health services and industry whilst retaining key Dstl expertise.**

Information Management

B5.14 The combination of hazard assessment, awareness of the threat and operational analysis is key to future capability planning. Within this, it is critically important to exploit knowledge of toxicology, dispersion, detection and data fusion to inform planning and decision support tools. Key requirements include improving the ability of UK Forces to operate flexibly and at high tempo in the presence of CBRN threats. Whilst interoperability is important and pursued where possible, differences in CBRN doctrine and concepts with our Allies mean that **the UK must retain control of the design and development of its CBRN information management systems, including warning and reporting tools.**

Electron micrograph of a lung capillary infected with the causative agent of anthrax

B5.15 The achievement of a timely warning capability is critically dependent on a suite of technologies, including sensor management systems linked to a command and decision tool (NBC BISA). Networking the outputs from a range of CBRN sensors and integrating the data with that from other sources (e.g. metrological sensors, direct observation) can reduce false alarm rates and increase user confidence. In the area of dispersion modelling, significant recent advancements have only been possible through collaboration with US programmes and this is likely to continue. MOD is working with academia and industry (including the Data and Information Fusion DTC) to develop improved algorithms and data fusion techniques for incorporation into the Integrated Sensor Management System (ISMS) and NBC BISA. **Collaborative research supporting ISMS and NBC BISA will continue for the foreseeable future to provide incremental improvements in capability.**



Output from Urban Dispersion Model showing spread of CW agent

L30 respirators – Dstl

B5.16 Over recent years MOD has invested in the development of a CBRN synthetic environment (the CBRN Virtual Battlespace) as a tool to underpin CBRN operational analysis. We will continue to develop this tool and will apply it more widely, to enable promising research ideas to be validated experimentally, equipment programmes to be de-risked, and appropriate training to be developed, all in a common representative context. **We will collaborate to link the CBRN Virtual Battlespace with other synthetic environments and high-level OA models used in MOD and to gain an interface with NEC, and we will seek further collaboration with academia and industry.**

Physical Protection

B5.17 With the impending introduction of new individual protective equipment (General Service Respirator (GSR) and MkIVa suit), which both provide a high level of CBRN protection, **the most immediate requirement is to focus research investment on improving aircrew protection and collective protection facilities.**

B5.18 There is a need to understand the trade-off between physical protection and operational degradation and facilitate translation of this knowledge into new equipment. It is particularly important that this work reflects the hazard levels expected in future scenarios rather than the legacy of cold war analysis and planning. **We will collaborate with industry, and academia where appropriate, to develop personal and collective CBRN protection systems based on materials and approaches that impose low physiological and/or logistic burden.** We recognise that the majority of material developments will occur for non-CBRN reasons. Industrial capability is increasing, with the demand for civilian protective equipment having a significant impact. Specific strengths in UK industry include regenerative filtration technology and individual protective equipment design. We aim to exploit these developments for MOD requirements where appropriate and achievable. In the longer term we aim to incorporate CBRN protection into standard military clothing and shelters.

Medical Countermeasures

B5.19 **Our long term (20 year) objective is to identify generic medical countermeasures against all toxic and infectious agents that may be used as CBRN weapons.** We recognise that this is ambitious so in the short term (5-10 years), some focus will remain on specific solutions such as vaccines and anti-toxins against particular agents of concern.

B5.20 Whilst the MOD has a very limited radiological countermeasures capability, research investment in the development of radioprotectants and/or radiotherapeutics is a relatively low priority. The strategy is to maintain collaboration with Allies, particularly the US, in this area. As the MOD has an effective suite of medical countermeasures to some chemical agents ('nerve agents') and an improvement to this capability is currently going through licensing and is expected to be in-service within 2-3 years, **the priority for the short to medium term (5-15 years) will be with the development of medical countermeasures to biological agents.**

B5.21 The strategy for a move towards generic countermeasures has increased the technical risk in the research programme. Generic therapies are also an objective of the civil sector and since MOD will never be able to afford a drug discovery programme, it is our strategy to adapt such therapies as they arise. The UK CBRN medical countermeasure research capability resides primarily at Dstl, but includes the Health Protection Agency and significant input from

a wide academic network. However, the ability to handle pathogens under realistic conditions, which is key to development of viable countermeasures, is extremely hazardous and limits non-Government research in this area. Furthermore, the commercial drivers in the UK for such a capability are very low, even with the increased awareness in the civilian counter terrorism sector. Current MOD policy is that all medicines administered to service personnel will be licensed: it is therefore vital that MOD supports an on-shore capability to manage and conduct clinical trials that will enable CBRN medical countermeasures to satisfy UK and EU legislative requirements. Due to the high costs of drug development and licensing we are reliant on collaboration and burden sharing with Allies. **The strategy for the development of CBRN medical countermeasures is to explore approaches from academia and SMEs, adapting them at Dstl and then seeking to share the burden of clinical trials and licensing with international and industrial partners.**

B5.22 The majority of CBRN agents will enter the body via the lungs (through inhalation of gases, vapours or aerosols) or the skin (by direct contact with vapours or liquids). There is a need for drug delivery technologies that target the medical countermeasure to the appropriate site within the body to optimise efficacy. **Whilst MOD will continue to invest in research into optimal formulations for candidate CBRN medical countermeasures, there is a healthy UK and off-shore capability to design and develop drug delivery technologies and MOD will rely on industry to provide this capability.**

Colonies of Yersinia pestis (Plague) bacteria growing on agar

B5.23 Medical countermeasures research, in common with the majority of hazard assessment research, will rely heavily on data derived from animal experiments for the foreseeable future. It is vital that an on-shore capability to breed a wide range of experimental animals is maintained, not only to support basic research but also to enable efficacy, toxicology and safety evaluation studies of candidate medical countermeasures during the licensing procedure. **As part of an integrated approach to CBRN medical countermeasures research, MOD will pursue reduction, refinement and replacement of animal experimentation as well as exploiting developments in academia and industry in this regard.**

Hazard Management

B5.24 Our aim is to identify technologies to facilitate better CBRN hazard management. This encompasses reconnaissance and survey, decontamination, demilitarisation and consequence management; the latter will increase in importance over the next few years. This areas draws heavily on hazard assessment research to provide a better understanding of the persistence of CBRN agents and, in particular, the residual hazard posed by biological agent contamination. The UK industrial base for technology development in decontamination is weak, with the majority of capability being led by organisations in mainland Europe with offices in the UK and although this technology area has very close synergies with the civilian CBRN CT programmes, it is assessed that this will take a number of years to have an impact on the UK supplier base. **There is a need to sustain the Dstl capability in hazard management in the short to medium term (5-15 years).**

B5.25 Recent research has indicated that alternative approaches, such as strippable coatings and tie-down solutions, combined with application of decontamination solutions, may be effective in providing a hazard management capability for platforms. **MOD will collaborate with industry to develop 'binary approaches' to contamination control and aim to support TDPs to de-risk potential hazard management capability solutions.**

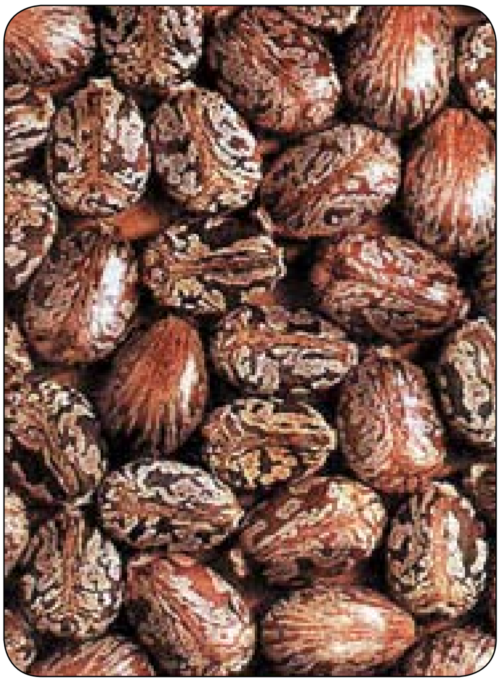
Test and Evaluation, Risk Management and Duty of Care

B5.26 The research and technology development outlined in this chapter is critically dependent on the sustainment of an on-shore capability to test potential technology solutions in realistic environments against actual CBRN agent challenges. Whilst there is widespread capability within the UK to test technologies against CBRN agent simulants, predominantly in ideal laboratory conditions, the military end-user needs the confidence that the capability solutions we provide will work in an operational environment. **For the foreseeable future, MOD will maintain the ability to assess technologies under realistic conditions, by continued research investment in Dstl and through collaboration with Allies to access their facilities. Where appropriate, MOD will allow academic and industrial use of UK facilities, such as ranges for 'live agent' field trials, pathogen handling facilities (including category 3 & 4) and materials testing facilities.**

B5.27 We have seen an increase in the need to consider informed risk taking and risk management. This includes the possible effect of exposure of personnel to all battlefield and environmental hazards, and legacy issues. It also requires more emphasis on possible gender differences. As the issue of CBRN widens to the civilian arena, there is an ever-greater drive for the determination of acceptable levels of contamination for both civilian and military personnel. With the trend of increasing post conflict hazards and a decreasing acceptance of the risk of exposure to CBRN materials, it is likely that civilian and military requirements will converge to mutual benefit in the future. This area is currently not well supported in the research programme but has wide implications for the determination of appropriate pass/fail criteria that industry derived equipments need to be designed and developed against. **Dstl will collaborate with industrial suppliers and Allies to agree a common approach to equipment evaluation and assurance and develop common standards where appropriate.**

The way forward for CBRN technology development

B5.28 **The two highest priority areas for research investment over the duration of this strategy are biological detection and biological medical countermeasures, in particular issues relating to through life capability management cost such as bio-consumables.** The funding allocated to these areas currently accounts for almost half of the MOD's CBRN research programme and the resultant programme is diverse and attempts to explore a widening range of technical solutions. Over the period of this strategy the aim will be to prioritise those technologies offering the greatest likelihood of generic protection against BW agents. Higher risk research will continue to explore novel approaches to generic protection against BW agents.



The Ricinus communis plant (left) and castor oil beans (from Ricinus communis zanzibariensis; right) – the source of ricin toxin

B5.29 **Significant capability gaps still exist in the area of physical protection and contamination control and there is a requirement to continue to support these areas. Any further diversion of funds from these areas to higher priority issues would leave these capabilities untenable and would have a major impact on our capability to test and evaluate technologies developed in industry against 'live agents' in realistic conditions.**

Development of Elimination and Disablement Policy

B5.30 Until recently the major focus of CBRN policy has been Arms Control, Preventing Supply, Deterring Use and Defending Against Use. As our policy extends to consider Elimination and Disablement, it is very important that MOD develops a strategy to support this. This area is highly reliant on international research collaboration and our Allies are recognised as leading in this area. Future needs in this area include understanding agent vulnerability, understanding the consequences of interrupting the supply chain and the ability to identify, at a distance, CBRN research and production facilities.

Interaction with Other Government Departments

B5.31 The Home Office leads a research programme aimed at meeting civilian CBRN requirements. Whilst it is accepted that the scenarios and requirements for civilian and military defence against CBRN materials can differ significantly, it is clear that the underlying science and technology is common. It is, therefore, essential that the Home Office and MOD research programmes avoid duplication and derive maximum mutual benefit from the activities each department supports. **MOD will continue to have an active role in the selection of research supported by the Home Office CBRN research programme and, where appropriate, will gain access to the output from this research for exploitation against MOD requirements. We will provide other Government departments access to all output from the MOD research programme (classification permitting) via the Home Office.**

Industry and Academia

B5.32 The overall aim is to achieve far greater awareness in industry of emerging technologies from the CBRN research programme in order to allay, where possible, industry's concerns over risky or immature technology. The implementation of the CBRN element of the DIS is aiming to develop a closer working relationship with the UK CBRN supplier base and identify a range of strategic industrial partners. **Whilst it is accepted that the sensitive nature of the research carried out in this domain dictates a requirement for control of information, increased effort will be directed to facilitate better communication to non-Government organisations and increase their involvement at an earlier stage of the research.**

Immediate Response Team on exercise

B5.33 Engagement with academia and RTOs is fundamental to the development of technology to meet the capability requirements for CBRN. Several mechanisms exist for engagement of academia including:

- Funded research via Dstl as integrator.
- Funded research jointly with the research councils.
- Collaborative research between consortia of Dstl, academia and industry.
- The use of independent advice in the scrutiny of technical output.

B5.34 In addition, in certain key areas such as medical countermeasures, UK universities and Dstl bid as consortia for overseas funding where the external fund-holder has similar or identical requirements to MOD. **Where possible the research programme will help facilitate the development of relationships between Dstl, academia, SMEs and industry. Over the course of this strategy further engagement with academia is intended with, significant increases in the area of biological detection and in Dstl/academia/industry collaborations.**

B6 Counter Terrorism

Introduction

B6.1 Counter Terrorism (CT) is a pan-Government activity, the policy responsibility for which sits primarily with the Home Office (for activities internal to the UK) and the Foreign and Commonwealth Office (for activities overseas). The MOD provides military support, and takes the lead, in those areas where military forces on operations are at risk from terrorist attack.

B6.2 The threat from international terrorism to the security and economic interests of the UK, its partners and its allies will continue for the foreseeable future. Moreover, the threat presented by terrorist networks continues to evolve rapidly. MOD must be able to conduct operations in the presence of the terrorist threat and be able to counter new threats as they appear.

B6.3 **The MOD Counter Terrorism Science and Technology Centre (CTSTC) is responsible for ensuring coherence across MOD's science and technology activities in support of CT. The CTSTC will seek earlier exposure of requirements to suppliers and will also encourage collaborative working between industry, academia and MOD.**

Engagement with Industry

B6.4 The sensitive nature of MOD's CT programmes has impeded the early exposure of MOD's science and technology requirements to industry. This, in turn, has impeded the transfer of knowledge from MOD funded research to the manufacturing base. In the future, MOD will engage with key List X suppliers much earlier in the research and development process to:

- Expose industry to future requirements so that informed investment decisions can be made.
- Confirm that any research is fit for purpose. This will also enable both industry and MOD to better understand the investment and resources required to increase the Technology Readiness Level (TRL), up to that required to meet MOD's capability requirements.

B6.5 **MOD will seek to access innovation within small and medium sized enterprises (SMEs) and RTOs within the United Kingdom and will encourage larger suppliers to do the same.** MOD recognises the advantages in both time and cost of adapting commercial of the shelf (COTS) equipment to meet operational needs. MOD also recognises that this can be difficult for SMEs with limited budgets, where appropriate, MOD will assist suppliers to adapt their products to meet particular requirements.

Engagement with Academia

B6.6 The current MOD funded CT programme is biased towards the higher TRLs at the expense of developing concepts that may underpin future requirements. In the future, MOD will actively encourage contributions from academia by seeking to ensure that a significant amount of the CT research programme is targeted at the 5-10 year time frame. This will markedly increase the opportunities for academic participation in the research programme.

Priority Technology Areas

B6.7 MOD's CT capabilities rely upon access to a very broad range of scientific and technological disciplines across the research and industrial base. The summary table below gives details of the priority technologies.

The Gas Tight Suit, used in combination with self-contained breathing apparatus

Table 1. Summary of Priority Technologies

CT Sub-System	Priority Technologies	National capability requirement (* see note at foot of table)
Systems Integration and Platforms	Systems integration, physical and electronic architecture to facilitate technology insertion.	System design, assessment, specification of interfaces. Deep understanding of integration issues and risks.
	Methods that enable easy interoperation with Coalition Forces	Intelligent Customer and ability to specify interfaces.
	Power sources - light weight - high energy density	Intelligent Customer. Specify, test & assess.
	Human Computer Interface	Intelligent Customer.
	Electro-Magnetic Compatibility	Specify, test and assess.
Sensors and Diagnostics	EO sensors in the visible and infra-red wavebands - Miniature - Low power consumption	Design, integrate and modify.
	Other sensors - particularly those able to detect and distinguish between different materials and components that terrorists might use.	Design, integrate, develop and modify.
RF Systems (see also C4ISTAR chapter)	Systems able to operate in a congested RF spectrum	UK needs to retain design authority for certain classified equipment
	Antennas - high efficiency - wideband	Design and integrate.
	RF amplifiers - high efficiency - wideband	Design, integrate and modify.
Information Systems (See C4ISTAR chapter)	Secure information architectures	Need to be able to accredit architectures
	Data compression	Understand specify, and integrate.
Explosive Ordnance Disposal	Weapons to disrupt terrorist devices	Full capability.
	Remote control vehicles, particularly autonomy aspects (see also Fixed, Wing, Complex Weapons, Maritime and Close Combat chapters).	Design & develop.
Special Weapons and Demolition Charges	Special weapons and demolition charges	Specialist knowledge to support design, specification and assessment.

(* Assured access to rapid turn-around, low volume system/ sub-system manufacture required for all priority technologies)

Systems Integration and platforms

B6.8 It is critically important that the various technologies required to support CT operations are properly integrated into systems and on to platforms. Achieving this will require research and development in a number of areas. However, two topics are worthy of additional comments:

- UK Forces will operate alongside those of other nations as part of a coalition. In many cases it will be necessary for UK equipment to interoperate with coalition systems. This will be a key driver for future equipment.
- Power sources continue to limit the capability that can be deployed away from fixed infrastructures. Industrial and academic power source developments will be monitored to identify those that may enhance CT capabilities. When potential power sources are identified they will be evaluated and, if appropriate, MOD will work with the supplier to develop or tailor the source to a particular application.

Sensors and Diagnostics

B6.9 Many of MOD's CT capabilities are enabled by sensing and diagnostic systems. Three points are worthy of note:

- **MOD will track commercial developments in sensors operating in the visible/near visible wave bands, paying attention to those that offer high resolution imagery, day and night, with low power consumption and low physical volume. Where appropriate MOD will work with suppliers to modify and integrate products for specific needs.** A key challenge will be to develop adaptive systems capable of providing stable imagery through heat haze.

- In the future, MOD may be threatened by improvised devices containing hazardous substances other than explosives. **Future research will investigate the opportunities to combine different detection capabilities, for example explosives detection and chemical detection. Understanding and developing technologies that are able to distinguish between substances, for example neutron imaging, will be a priority.**

- In addition to systems that are able to detect and identify the payload of an improvised device **MOD will continue to develop technologies that are able to detect the other components associated with improvised devices.**

Forensic scientist in the laboratory at Dstl

B6.10 In all cases the CT sector will draw on sensor technologies developed elsewhere in MOD's programme.

Radio Frequency Systems

B6.11 Radio frequency (RF) systems underpin a large number of MOD's classified CT capabilities. **MOD will develop through its research and procurement programmes expertise in the design and manufacture of RF systems and sub-assemblies on-shore in the UK.** Three areas are of particular importance:

- Developing systems that are capable of operating in the increasingly congested electro-magnetic spectrum, for example, examining the utility of the 'cognitive radio' approach.

- The continuing need for efficient antenna systems able to operate over wide bandwidths in sub-optimal conditions.

- The design and development of efficient wideband power amplifiers.

B6.12 A number of related technologies remain important to MOD's CT capabilities.

- Signal processing, especially the detection and characterisation of weak signals.
- Waveform design to meet specific requirements.
- Circuit miniaturisation.
- Understanding evolving communications standards.

Information systems

B6.13 Two technology areas are important for CT operations:

- Developing and understanding information and accredited security architectures that enable a controlled and secure flow of information, as part of a Network Enabled Capability for Special Forces. There is an important synergy here with C4ISTAR requirements.

- The technology of data compression, especially the development of low power consumption techniques suitable for use with remote sensors.

Explosive Ordnance Disposal

B6.14 Explosive Ordnance Disposal (EOD) is an essential element of MOD's CT capability, and in addition to the sensor and diagnostic systems, outlined above, relies upon two key technologies:

- Weapons that can efficiently disrupt suspect devices with minimal collateral damage. **MOD will continue to invest in research and development to ensure that it can defeat future improvised threats.**

- Remote controlled vehicles (RCVs) are required to deliver weapons and sensors to the suspect device as part of EOD operations. **Previous research and development has concentrated on improving the RCV platform, future work will focus on reducing the RCV operator's workload through increased autonomy.**

Carver 3 – prototype RCV

Special weapons and demolition charges

B6.15 MOD will continue to require access to expertise in special weapons and demolition charges developed to meet evolving requirements.

The Way Ahead for CT

B6.16 **MOD will engage with key suppliers much earlier in the research and development process to enable industry to make informed investment decisions.**

B6.17 **Where appropriate MOD will assist small and medium sized enterprises to adapt their products to meet particular CT requirements and will actively encourage contributions from academia to support future CT programmes.**

B6.18 **The MOD is reviewing its entire CT programme following the formation of the Counter Terrorism Science and Technology Centre and will produce a more detailed, classified technology strategy upon completion of the review.**

Semtex print on fine cotton fabric at x500 magnification

B7 Complex Weapons

Introduction

B7.1 The complex weapons area covers a broad range of technologies reflecting the increasing diversity and increasing use of complex weapons in the air, maritime and land environments.

B7.2 The DIS defines CW as those strategic and tactical weapons reliant upon guidance systems to achieve precision effects. This chapter encompasses air launched, surface launched and underwater weapons.

Multiple Launch Rocket System (MBDA UK Ltd)

B7.3 Several national requirements can be identified from DIS:

- The ability to design and integrate weapons with platform and sensors. .
- Autonomy over mission critical controlling software.
- Exploitation of network enabled environments.
- Weapons effectors (and in particular Directed Energy Weapons and torpedoes).
- The ability to develop counter-countermeasures.

B7.4 Overlying the critical technology thrusts are the needs to:

- Understand threats from technology proliferation.
- Respond to urgent operational requirements.
- Undertake projects within legal and international frameworks.

B7.5 And there are two other cross-sector factors:

- The availability of complex weapon processing facilities.
- Through life capability management and inventory support.

B7.6 Energetic Materials are only addressed within Complex Weapons as part of critical sub-systems i.e. payload, explosive train and rocket propulsion. Wider energetic materials issues are dealt with in the General Munitions chapter.

B7.7 A number of broad top-level conclusions can be drawn concerning the overall picture for CW:

- There are few areas of critical national importance where we do not possess an adequate UK capability. The issue is therefore how to sustain our capability given a limited research budget and an equipment programme forward investment plan that sharply reduces in the medium term.

- Many technologies of national importance also have reasonable commercial attractiveness, although few can be sustained on a commercial basis alone. This underlines the importance of having a joined up MOD/industrial technology investment plan. Exceptions include stealth, DEW, radiation hardness/ non-nuclear EMP/EMC, aspects of test and evaluation software/SE and weapons aerodynamics. These are areas where MOD will need to take the lead in determining the investment strategy.

- There is significant potential for innovation in virtually all of the important technologies in this sector, confirming the growth potential for continued/ enhanced research investment.

Priority Technology Areas

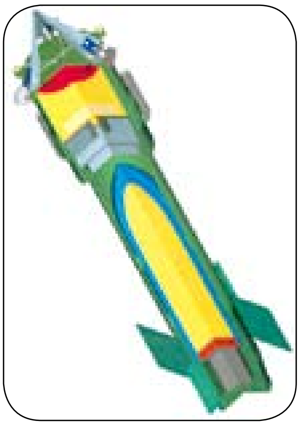
Table 1. Summary of key technologies

Complex Weapon Sub-System	Priority Technologies	National Capability Requirement	Potentially through collaboration
Concept Generation & System Design/ Integration	Systems Integration	System Design, assessment, specification of interfaces. Deep understanding of integration issues and risks, technology insertion and through life management.	
	Modelling/ Assessment Tools	Access to validated models, SE & HWIL facilities.	
	Open Architectures	Understanding, design and specification	
	Platform Integration and weapons clearance including Electro-Magnetic Compatibility testing and safety assessment.	Safety and duty of care issues need UK assessment capability	Share experience on safety and weapons clearance issues collaboratively
Software	Safety Critical.	Design, develop, maintain and upgrade software for CW	
	Autonomy	Design and develop to meet UK Conops, RoE and safety requirements.	
	Mission Control/ Planning	As autonomy above.	
	Fire Control, Safety & Arming & Fuzing (software not hardware)	Design and develop	Can collaborate on these topics but need to retain national capability
	Image and Signal Processing	Design, develop and assess – critical UK capability and strength.	
	Guidance, Navigation and Control	As signal processing above	
	Health and Usage Monitoring (software not sensors)	Design and understanding of algorithms based on deep understanding of lifing issues.	
NEC	Datalinks, communication, crypto, weapons integration in NEC environment	Thorough understanding of network integration issues	Share experience on these issues collaboratively
Propulsion	IM Rocket Motor	Design and Manufacture of IM compliant systems. Understanding of ageing process. Duty of Care issues.	Composite case technology and composite propellants
	Electric Motors/ Torpedo Propulsors	Understanding and integration of electric propulsion Design capability for propulsors.	
	Ramjet/Scramjet and Pulse Detonation Engines	Intelligent Customer only. (See comments re high speed weapons in main text.)	Collaboration desirable
	Other Propulsion Topics e.g. Igniters, turbo-jets, internal combustion	Systems integration capability.	
Payloads/ Effectors	Lethal - warhead, fuze, Safety & Arming Unit, initiator, explosive train including g hardened miniaturised electronics and MEMS	Critical safety, duty of care, integration, performance and life assessment issues. Need design, assessment and integration.	
	DEW – particularly RF and Laser dazzle and damage.	Emerging disruptive area, UK needs full capability.	
	Non-lethal	Technology watch only.	
Aerodynamics and Airframes	Aerodynamics - knowledge, skills, modelling tools and facilities (i.e. wind tunnels)	Design/ modelling capability including code generation/ understanding of fundamental physics. Guaranteed access to wind tunnel facilities.	
	Hypersonics	Intelligent Customer only. (See comments re high speed weapons in main text.)	
	Hydrodynamics (see also Maritime chapter)	Design/ modelling capability including code generation / understanding of fundamental physics (linked to wider Maritime requirements).	
	Structures and Materials – e.g. lightweight materials, RAM, morphing structures, packaging, materials and memory alloys	Design, assessment and understanding of through life issues.	

Complex Weapon Sub-System	Priority Technologies	National Capability Requirement	Potentially through collaboration
Survivability	Stealth – RF and EO (above water), acoustic (torpedoes only)	Design, understanding, assessment (incl through life support) and, for RF/EO, manufacture	
	Counter-countermeasures - including seeker robustness to spoofing, GPS anti-jam, data-link integrity, warhead/ fuzing design for CDAS etc	Design and assessment capability	Sub-system research; develop sensor hardware
Sensors	Off-Board	See C4ISTAR and Cross-Cutting Technologies chapters for sensors. For CW need understanding of network issues and performance trades.	
	On-Board – RF, EO/IR, SAL, LIDAR, Domes/ Windows, Acoustic (torpedoes), Magnetic	Sustain niche capability in domes. See Maritime chapter for acoustic.	Sustain design and development capability for RF, EO/IR and possibly Lidar -addressed through collaborative research while retaining key UK expertise

Concepts Generation and Systems Design and Integration

B7.8 A number of key national technology requirements have been identified:



Design of the Urban Assault Weapon

- Software (algorithms etc) and the understanding of the underlying physics and design principles for complex weapons. This is generally more important than the ability to design and manufacture component hardware.
- The capability (i.e. facilities, knowledge and skills) to undertake simulation/ modelling/synthetic environments and hardware-in-the-loop (HWIL) in support of the entire weapon life cycle.
- Duty of care and safety require a detailed understanding of key technologies to ensure all munitions, meet an acceptable standard. This includes insensitive munitions (IM) design methodologies and a thorough understanding of through life/service life prediction/assessment issues.
- Security issues to ensure that the UK retains sovereign control of its weapon systems and can understand threats/countermeasures to its systems.

B7.9 Design and integration of sub-systems is a core skill to enable the UK to meet national capability requirements and to upgrade and support existing systems through life. DIS highlights the need for the UK to retain a critical mass of design/integration expertise on-shore to allow the UK to act independently. Without this core capability, the ability to exploit the other UK technologies will be dependent upon off-shore commercial decisions; therefore it is the highest priority capability to retain in the complex weapons area. **Research investment will be focussed on developing tools and understanding and generating concepts, but TDPs will need to be developed to de-risk selected solutions, together with targeted equipment programme investment to enable exploitation.**

B7.10 The ability to understand, design and specify Weapon and Missile System Open Architectures is a vital national need. **This enables technology insertion and facilitates collaboration and the integration of off-shore sourced sub-systems whilst retaining UK control at the system level.**

B7.11 **The UK has a sound capability in the area of simulation, modelling and HWIL testing. This can be partly sustained by an active programme of research, although these skills need to be exercised through demonstrator and development programmes.** The research programme supports the former but there is a critical shortfall in the latter. The DIS Complex Weapons Implementation Team (CWIT) activities are seeking to address this issue. Coordination of MOD and industry research investment will also be important.

B7.12 Understanding weapon/platform integration issues is key both in terms of dynamic performance/loading, and safety issues. In particular, the ability to exploit the technologies identified in this strategy depends upon the ability to integrate new, or modified, weapons into platforms.

Brimstone anti-armour weapons on a Tornado

B7.13 **At present the cost of safety clearance of new or modified weapons on platforms is prohibitive and risks seriously undermining the ability to implement this strategy.** In order to address this issue the UK requires:

- A detailed and validated modelling and simulation capability.
- A jointly agreed MOD/industry process, making maximum use of the predictive capability, aimed at providing cost effective clearance of weapons systems.
- A thorough understanding of the risks which the weapons integration process seeks to mitigate and the associated cost benefit.

B7.14 **To this end MOD will review its weapons integration policy and procedures with the aim of reducing cost where appropriate and will facilitate a joint MOD/Industry research programme to inform this process. EMC and appropriate test facilities will be sustained through the current Long Term Partnering Arrangement (LTPA) for test facilities.**

Software

B7.15 The skill and knowledge to design, develop, maintain and upgrade software is a vital skill. In particular the need to fully understand safety-critical software issues is paramount in facilitating certification and safety clearance of systems. Key CW specific skills/technologies requiring targeted investment are:

- **Autonomy**. The UK needs a national capability to design and develop software for autonomous systems as there are likely to be specific national requirements arising from national Concepts of Operation, Rules of Engagement, and safety certification.

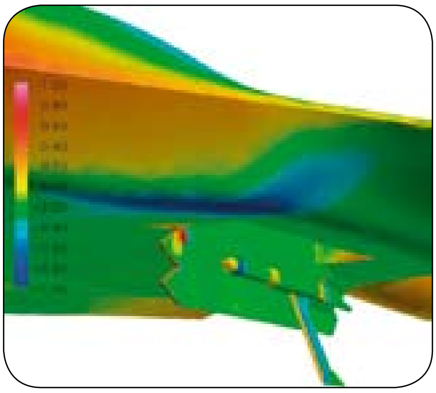
- **Mission Control/Planning.** Increased emphasis on time critical engagement and on RoE / legal and ethical issues highlight this as an area for increased investment.

- **Safety and Arming**. There is an imperative to understand this technology both to support the qualifications process an to ensure that new designs are compliant with evolving safety standards. In the future, programmable and NEC-enabled fuzes will bring safety critical software issues.

- **Image and Signal Processing**. This technology determines the performance of seeker/ guidance systems. This is vital to sustain as the importance of clutter rejection in complex environments increases. Modest research funding should facilitate this.

- **Guidance Navigation and Control**. The UK has a strong capability in this area but there is a need to enhance further particularly in the light of legal considerations for weapons release and to understand the implication of the networked environment. Research investment supported by targeted demonstrator programmes will be made.

- **Health and Usage Monitoring Systems (HUMS)**. Development and exploitation of HUMS is driven by potential whole life cost reductions and is an important issue for safety reasons. MOD will develop its strategy in this area to focus research funding on understanding lifing issues; collect data on in-service systems; and early investment in HUMS in acquisition in order to reap long term benefits.



Computational prediction of weapon release characteristics

The Network Environment

B7.16 The influence and opportunities presented to Complex Weapons by NEC is a critical technology issue. **A thorough understanding of the opportunities and risks posed by integrating complex weapons in a networked environment is required as a national UK capability.**

B7.17 Collaborative programmes with international partners can facilitate the generation of the knowledge base through the sharing of data, but development and retention of an indigenous expert knowledge base is vital. Key issues which will see ramped up investment are:

- In-flight target re-designation.
- Alternative lethal effect selection.
- On-board/Off-board sensor trade-offs.
- Man-in-the-loop/autonomous trade-offs.
- Collaborative weapons operation.
- Battle Damage Assessment information passage.

B7
Complex Weapons

Propulsion

B7.18 **IM Rocket Motor**. The UK has key niches in this technology, but runs the risk of losing expertise in such areas as composite case and composite propellants technologies. It is vital to at least keep core understanding of these areas.

B7.19 There is a need to mature work on (IM compliant) controllable thrust and on understanding ageing processes in order to meet future capability needs. To fulfil MOD's commitment to safety and duty of care it is considered vital to sustain the capability to design and manufacture IM compliant systems in the UK. MOD will coordinate and enhance its research programme in this area and work towards a series of weapon TDPs.

B7.20 **High Speed Weapons**. Without a defined military requirement for HSW, the lack of UK capability in key areas and the pressures on R&D funding, it is recommended that UK should not pursue an indigenous capability in HSW. MOD will therefore take the risk that alternative concepts can deliver the required capability or that suitable systems can be bought off the shelf. Thus, MOD will undertake the minimum level of research commensurate with maintaining Intelligent Customer status and technology watch in HSW technologies.

B7.21 Technology awareness of hypersonic ramjet propulsion will be maintained through the collaborative Sustained Hypersonic Flight Experiment (ShyFE), which is due to complete in 2009. We will then review the future options for the area.

B7.22 **Other Propulsion Topics.** For propulsion related technologies of igniters, turbojets, and internal combustion engines it is judged that technology development can be left to commercial considerations.

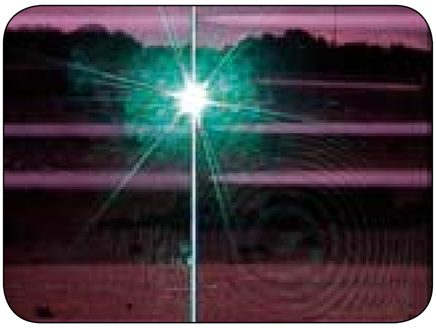
Payloads/ Effectors

B7.23 **Lethal Payload.** It is important to maintain UK understanding in this area as there are critical safety, integration, performance and life assessment issues. MOD will sustain and focus investment on products with exploitation potential, strongly linking research investment into weapons demonstrator programmes in future. In particular:

- Improved performance hard target penetration.
- Tuneable/scaleable effects warheads.
- Associated fuze/SAU component technologies.
- Miniaturisation of components for future systems.
- Pull through of miniaturised, g-hardened electronics and MEMS technologies.

B7.24 In the short/medium term there are programmes addressing the hard target technology aspects, therefore the most immediate shortfall is in the maturation of tuneable effects technologies. KE penetrators has been identified as an area where the UK could afford to withdraw and rely on commercial supply.

B7.25 **DEW (including payloads)**. This emerging area of technology covers a broad spectrum of concepts within which the UK has world leading niche capabilities. Understanding of the implications of DEW across all Lines of Development is key since this is a potentially disruptive technology. **In view of this it is considered vital that the UK retains a capability in RF DEW systems (and associated vulnerability and lethality modelling) and highly desirable that a national capability is retained on defensive laser (damage and dazzle) systems (design, assessment and integration aspects).** Increased investment in DEW will be required to achieve this but, as a minimum, investment will be targeted initially toward RF systems whilst evaluating emerging technology in the Laser Damage area (such as fibre bundle lasers) through limited, low TRL, research funding. Extant EOCM demonstrator programmes in the Air and Maritime domains should sustain laser capability in the short term. In the longer term MOD will consider the need to increase funding on LDW once the utility and risks of the technology are better understood.



Dazzle from a laser system

Modelling of the millimetric wave anti-personnel RF-Directed Energy Weapon

B7.26 **Non-Lethal**. We will need to have the ability to integrate a variety of payloads into complex weapons including non-lethal. In addition we will maintain a low level technology watch on non-lethal technologies in order to assess their operational utility.

Aerodynamics/Airframe

B7.27 **Aerodynamics**. The UK has a good capability in this area which will be sustained through continued research investment in weapons aerodynamics, building on the skills base associated with air platform aerodynamics.

B7.28 It is assumed that the required sub-sonic and trans-sonic wind tunnel facilities can be sustained on a commercial basis. In the case of super-sonic wind tunnels, most UK facilities are moth-balled and, as good facilities exist in Europe, MOD will not specifically invest in maintaining on-shore facilities.

B7.29 **Structures and Materials.** A thorough understanding of structural and materials issues is vital to weapons design and through life support. Pull through of new materials technologies is important in areas such as:

- Lightweight materials.
- RAM.
- Morphing structures.
- Packaging.
- Shape memory alloys.

Survivability

B7.30 **Stealth**. An important technology area where collaborative work is possible, but where there is a need to maintain an on-shore capability. MOD will review the case for increased research investment, linked to air platform programmes, leading into weapon TDPs to address manufacturing issues and through life support issues. Design tools and core knowledge and understanding is shared with the air platform community and the forward programme needs to be planned as a coherent whole. MOD has mechanisms in place to achieve this working with industrial partners. Emerging technologies in the area of active stealth need to be monitored and pulled through as appropriate.

B7.31 **Counter-Countermeasures (CCM)**. This area aims to maximise the robustness of UK weapon systems to countermeasures. A broad understanding and ability to design CCM systems is a key national requirement, but this can generally be addressed in collaborative programmes through sub-systems research (warheads, seekers, guidance and fuzing etc). Specific technologies will generally be addressed as part of individual sub-system design:

- Seeker robustness to spoofing.
- GPS anti-jam.
- Data-link integrity.
- Warhead/fusing design.

B7.32 These will be underpinned by a low level technology watch for emerging counter-measure technologies.

Sensors

B7.33 **Off-Board**. Off-board sensor technologies are covered in the Cross-Cutting Technologies chapter. The use of information from sensors and the associated datalinks are key CW issues and will be addressed through the current MOD programme on Weapons NEC research and experimentation.

B7.34 **On-Board.** The UK has a good capability in sensor technology for weapon seekers and this position needs to be sustained; the priorities being in the areas of RF and imaging EO/IR sensors. This will generally be addressed through collaborative research programmes (while retaining key UK expertise), and introducing weapon TDPs to pull through selected solutions. Semi-Active Laser (SAL) technology is considered important but relatively mature whilst magnetic and acoustic sensors (excl UW applications) are of lower priority. LIDAR is an emerging area which may offer specific advantage for the UK to provide high confidence in target identification without the manpower implications of SAL.

B7.35 For an autonomous weapon where improvements in target discrimination are a priority, significant military benefits can be realised through the use of multi-mode and/or network enabled sensors, together with data fusion technologies. Imaging fuses, and guidance integrated fuse technologies are key enablers for fire control of selectable-tuneable warheads. The UK has a niche capability in diamond domes for long-wavelength IR seekers, and dome and window (frequency selective surface) technology, which will be sustained through developing pull through of the research. More work is needed to establish exploitation and procurement routes, and this may lead to requirements for TDPs in the future.

B7.36 Counter countermeasures and image/signal processing are a key national requirement. However, an international collaborative approach to develop sensor hardware is appropriate providing that an indigenous design and development capability, including access to firmware, can be maintained.

B7.37 Research funding (RF, EO/IR, LIDAR) needs to be sustained to develop laboratory hardware; the pull through of technologies into seeker sub-systems and weapon systems will need integrated planning.

The Way Forward for Complex Weapons Technologies

B7.38 Emerging technologies will be identified , de-risked and assessed through the Anglo-French Innovation and Technology Partnership (ITP) on Materials and Components for Missiles.

B7.39 One of the aims of the ITP is to deliver the research needs of the UK and France whilst building the technology base for future European guided weapon capability. Greater collaboration within Europe is seen as essential and the ITP represents the first step in this process. However the opportunities to mature the more promising technologies are limited by the relatively low levels of technology investment in this area. This implies that a re-distribution of current resources from low to high priority areas may not be sufficient to implement the strategy. Therefore MOD will develop its Complex Weapons technology strategy to consider changing the current Equipment Programme assumptions in terms of development, rather than off-the-shelf acquisitions, as well as further prioritisation of the areas for investment.

B7.40 This will require consideration of the required investment for each of the priority areas addressed above, and development of a plan for a series of technology demonstrators to assist with the integration of technologies to meet specific Equipment Programme needs. This will further develop individual technologies but also address the most important issue of understanding integration risks and maintaining a national systems integration and design capability.

B7.41 As the DIS implementation work is taken forward and, in particular, the MOD relationship with Team CW is developed to seek a strategic partnering arrangement, the research element will form part of the implementation plan. Team CW will be a key stakeholder for early, low TRL, research and as the more promising technologies are matured, Team CW will need to play an active part in the programme in order to ensure full exploitation of the research investment.

General Munitions and Energetics Technologies

Introduction

B8.1 The DIS defines General Munitions as those "simple munitions that do not tend to require interventionist maintenance procedures. The technology is based primarily on energetics and where intervention is necessary it is simple and requires generic engineering capability." It is important to recognise, however, that the distinction between General Munitions and Complex Weapons will become progressively blurred as low cost guidance technology develops and the user demands more controlled terminal effects.

B8.2 The DIS also recognises that despite the increased use of precision complex weapons, modern military operations often still require highly trained and motivated service personnel to engage in combat at a very personal level. It is in such engagements that high quality general munitions, including Small Arms Ammunition (SAA), are essential to provide the volumes of fire and the 24-hour, all weather capability required to suppress, neutralise and demoralise enemy forces. Although the increased use of simulation in training and other effectors on operations may reduce the overall volume of general munitions required, maintaining assured access to a timely and adequate supply of safe, effective munitions remains a key factor in maintaining UK operational sovereignty.

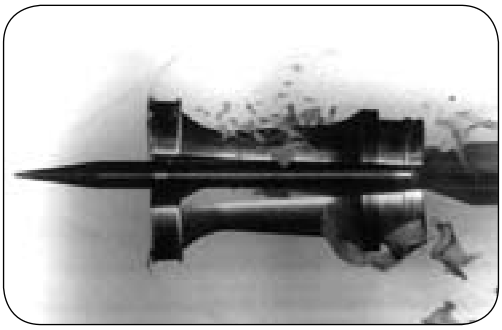
B8.3 To address this and other key issues the DIS identified a number of required national capabilities in the following areas, subject to value for money assessment:

- Systems Design.
- Systems Development.
- Systems Manufacture.
- Maintaining System Capability.
- Test and Evaluation.

42 Commando Royal Marines provided security in Helmand Province

B8.4 Analysis of the DIS also highlights that an increasing challenge for R&D is not simply to provide access to appropriate technologies but to play a central role in the safe, responsible and cost effective through life management of the munitions inventory. Essential to this is access to the right scientific and technological skills base both within the UK and through collaboration with other nations.

B8.5 In the longer-term future, standardisation on the choice of weapon systems and associated ammunition with our allies will benefit MOD and industry by opening access both to and from wider markets and promoting greater economies of scale. However, in the short to medium-term, continued assured access to bespoke, legacy designs of ammunition is essential to maintaining operational capability. Such access cannot be sustained through reliance on pure market forces and this has resulted in a number of Partnering Agreements between MOD and Industry, most notably the Framework Partnering Agreement (FPA) with BAE Systems Land Systems, who supplied 80% of the General Munitions requirements in FY 04/05.



Firing using a sabot

Priority Technologies for Munition Systems

B8.6 General Munitions and Complex Weapons share a number of common technologies, priorities and technology drivers not least those associated with their energetics content, performance requirements and need to fulfil Insensitive Munitions (IM) criteria, as defined in STANAG 4439.

Table 1. Summary of Priority Technologies for Munition Systems (including all General Munitions Categories and Complex Weapons)

Function	Priority Technologies	National Capability Requirement	Potentially through collaboration
Design	Intelligent Design	Integration with platforms and weapon system. Integrated modelling for design and assessment. Effective Certification processes	Collaborate on open architecture designs for Technology Insertion, management of obsolescence, reduced whole life costs.
Safety	Insensitive Munitions and Munition safety	Ability to interpret test data and assess munitions safety or IM status. IM Design and Development in accordance with IM Implementation Plan (IMIP)	Collaborate on fundamental S+T underpinning IM design and assessment, packaging and mitigation.
Performance	Effect and Consequence Modelling	Planning of effects based operations. "Lethality models." Collateral Damage Assessment.	Collaborate to achieve validated modelling techniques and other tools to support above, including a "launch to consequence" framework.
	Precision Effects	"Lethal payload" design and assessment. Understand routes to achieving multiple and potentially scaleable, or tunable effects to match the target.	Collaborate on fundamental S+T, including modelling and simulation, technologies leading to less than lethal effects, and understanding the military utility of blast and novel damage mechanisms.
Life	HUMs and Life Management Technologies	Prediction of safe and operational life, interpretation and implementation of failure and ageing algorithms Health and Usage Monitoring (HUMS) interface with logistics management network. Management, surveillance and NDE of munition stockpile. Munition storage and "in service" maintenance.	Collaborate on supporting hardware and sensor technology, long life power sources, techniques for generation of algorithms.
	Disposal technologies	EOD Minimum onshore logistic disposal capability Intelligent decision maker on future "environmentally friendly" disposal techniques.	Collaborate on fundamental S+T underpinning above, technologies for reducing munition environmental impact.
	Test and Evaluation	Access to facilities meeting UK standards.	Shared access to acceptable facilities.

Intelligent design

B8.7 There are areas of significant commonality in the design philosophy required for General Munitions and Complex Weapons. It is essential for all munitions that key aspects of their design and whole life management are thoroughly understood by the supplier and MOD. **The MOD will use its research programme to develop a shared awareness of critical design parameters with Industry and encourage joint investment in critical munitions technologies.**

B8.8 The past twenty years has seen a growth in the scientific modelling expertise that underpins the weapons and munitions area to the extent that it is seen as a real UK strength both nationally and by our international partners. It has progressed to a genuinely predictive tool that is gaining more widespread usage. To date it has been used by MOD to support its status as an intelligent customer/decision maker and as a responsible owner/user. **We will continue to actively work with Industry and international partners to develop a common framework for a Unified Weapon Modelling Capability that can be exploited for both assessment and design.** Current efforts are concentrated on developing a common engineering model framework but we have a longer-term goal of an integrated hierarchy of physics and chemistry based models linking into engineering models with an ultimate interface with operational analysis tools. This approach has been successfully demonstrated in understanding the military utility of blast, particularly in the urban environment.

Insensitive Munitions

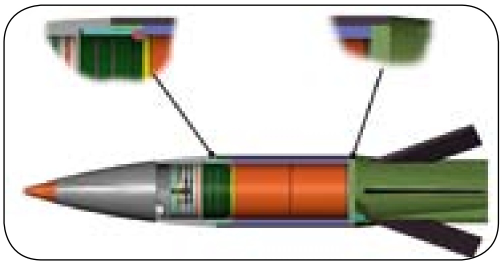
B8.9 Designing for safety is a well-established skill within the UK supplier base as is demonstrated by the progress towards fully implementing an IM inventory, mainly through cast cured Polymer Bonded Explosives; Low Vulnerability Ammunition (LOVA) gun propellants; IM Rocket Motors; mitigation technologies; and packaging designs. A thorough understanding, derived through past and ongoing research, of the influence of energetic materials and munition design on safety risks has allowed such risks to be minimised. This world class IM and energetics expertise, coupled to the professionalism of UK armed forces, has led to an enviable UK munitions safety record. The MOD will continue to discharge its responsibilities as a Responsible Owner and User of munitions by sustaining access to these skills

and expertise[1]. **Key energetics technical capabilities will be sustained via a National Energetics R+T Contract commencing in 2007. This will also contain elements of IM technology de-risking activities.**

B8.10 The MOD is committed to the introduction of IM compliant munitions into service and it is anticipated that nearly 50% of the munitions inventory will be IM compliant by 2010. **The Joint Insensitive Munitions Strategy Group (JIMSG), which also includes industrial representation, will continue to oversee the MOD Insensitive Munitions Implementation Plan (IMIP).** Funding for IM Technology Demonstrator Programmes, Technology Development within individual Equipment Programme lines and other technology de-risking activities will be prioritised in the short-term balancing opportunity, affordability, risk and benefit.

Munitions Performance

B8.11 UK's ability to design munitions to attain traditional performance goals will be challenged by the increasing need for flexibility in engaging with a wider range of targets under strict rules of engagement, and the need to provide easily deployable light- and medium-weight forces with sufficient lethality to produce rapid military and political effect when required. Designing warheads and overall munitions for precise effects with minimum collateral damage is a high priority area for both General Munitions and Complex Weapons areas. Such effects may include "less than lethal", multiple and potentially scaleable or "tuneable" effects. In the case of "tuneable" internal blast effects, research is already underway to investigate the critical explosive formulation parameters required to optimise the coupling to structural targets. This has only been made possible by a deep scientific understanding of, and ability to model, internal blast phenomena and structural response. **The whole area of lethal (and less than lethal) payload design will be taken forward in conjunction with the Complex Weapon area, and will underpin UK's capability to engage in effects based planning and effects based operations.**



Lightweight Artillery Munition design drawing

B8.12 MOD will increasingly draw on science and technology skills to assess the desired effectiveness and possible consequences of weapon use, both for General Munitions and Complex Weapons. **Robust "Lethality Models", linked to operational analysis tools must be maintained onshore, supported by scientific models from wider suppliers and collaborators.** These "Lethality Models", which form part of the Unified Weapon Modelling Capability, include collateral damage assessment models and should progressively incorporate less than lethal effects. In terms of assessing unintended consequences, the factors controlling environmental impact and potential toxicological effects are becoming better understood and are incorporated into assessments of use[2]. Access to the skills required to undertake such assessments is seen as increasingly important, particularly where usage has the potential to create controversy, such as in the case of Depleted Uranium (DU) kinetic energy penetrators[3].

Munitions Through-Life Management

B8.13 This is an area of increasing importance to MOD since there is significant potential for reducing whole life costs, through expert management of the stockpile. It is also where MOD's legal obligations as a Responsible Owner of Munitions are most prominent. **We intend to promote a "design for life" philosophy in order to achieve better whole life costs through a capability to predict and control factors influencing munition life, together with an ability to cost effectively minimise environmental impact.** This latter aspect would be achieved through designing, where practical, for ease of disposal or recycling at the end of service life.

B8.14 IM remains important in a whole life context, since a thorough understanding of the hazard/IM characteristics of individual designs enables MOD to undertake cost-effective safety management of munitions at all stages of their life cycle.

B8.15 Whole life management technologies and underpinning scientific understanding are required to manage what are effectively limited life consumables. These include:

[1] The Terminal Effects and Energetic Materials Advisory Committee (TEEMAC) Annual Report, 2005 notes that accidents are more likely to occur in countries that have lost expertise. In the period 2000 to 2004 well over a thousand people were killed world-wide with thousands more injured. 118 were lost in one incident alone, - the sinking of the Russian submarine, Kursk.

[2] All munitions are assessed for compliance against Health and Safety and Environmental legislation, as well as International Law prior to introduction.

[3] The MOD is conducting a DU research programme based on a Source: Pathway : Receptor methodology and subject to Independent Peer Review. Unclassified results of the programme will be published on the MOD website, from late 2006 onwards.

- Understanding failure mechanisms, their consequences and relationship to environmental factors such as temperature, humidity, vibration and shock. Generation of failure algorithms to predict remaining life for individual munitions. **Research on the whole life assessment of energetic components is already underway and will continue under the National Energetics R+T contract.**

- Assessment and control of the storage and transport environment, to accurately predict and maximise life. De-risking activities on Munition Environmental Data Logger Systems (MEDLS), or HUMS, capable of recording, interpreting and down loading environmental data commenced in 2006.

- MEDLS will be deployed in unit loads or individual packaging, but our ultimate aspiration would be for MEMS-type HUMS units integrated into individual munitions for high value assets, such as Complex Weapons. The ability to link to the network and translate the algorithms into life predictions remains the key facet, rather than the hardware.

- Design of packaging to minimise logistic burden whilst protecting munitions from undesirable life limiting external stimuli. Packaging can also form part of an IM solution.

- Technologies that minimise the need for intrusive maintenance procedures by MOD, such as long life power sources in MEDLS, effective non-destructive evaluation (NDE) and surveillance procedures.

B8.16 We also need to maintain the technical skills that underpin an operational Explosive Ordnance Disposal (EOD) Capability (see also Counter-terrorism chapter).

B8.17 **In the short term, we will sustain the minimum necessary onshore logistical disposal capability, as identified by the DIS. For the longer term, we will continue to use the research programme to investigate "environmentally friendly" disposal/recycling technologies required to meet increasingly stringent environmental legislation.**

Test and Evaluation

B8.18 An integrated test and evaluation capability is essential to MOD's needs. Key is the ability to interpret and make effective use of the derived test data. In practice, test results are only valuable when the tests are directed to meet specific UK needs. As such, overseas test results are not always acceptable and an impartial UK test and evaluation capability remains a vital requirement.

Stills from a firing trial of the Lightweight Artillery Munition

Priority Technologies for General Munitions

B8.19 General Munitions can be split into the four product categories:

- Small Arms Ammunition (SAA).
- Medium and Heavy Calibre Munitions.
- General Explosive Stores and Demolitions.
- Pyrotechnics.

B8.20 The Medium and Heavy Calibre Munitions category, and to a lesser extent SAA, represent the areas where operational sovereignty and assured supply needs are of the greatest concern[4] and thus are largely covered under the Framework Partnering Agreement (FPA).

[4] *See DIS Chapter B6 and HC 824 House of Commons Defence Committee, The Defence Industrial Strategy, Seventh Report of Session 2005-06: - Chapter 8 and supporting evidence.*

Table 2. Summary of Priority Technologies for General Munitions

Category	Priority Technologies	National Capability Requirement	Potentially through collaboration
SAA, Medium and Heavy Calibre	System Integration	Design Authority for "legacy munitions" where UK is design authority for the relevant weapon system or platform Design and integrate with the weapon interface and platform. Understanding of internal and intermediate ballistics Understanding of accuracy issues; external ballistics, course correction. Understanding of critical design parameters Packaging design and development. Final assembly – Fill, assemble and pack Intelligent customer for non-UK components and materials Surge production capability, if required to minimise stock holdings.	Underpinning S+T
	"g hardened" payload	Lethal payload, including Kinetic Energy projectiles, design, development and manufacture on case specific basis e.g. under Project MASS. Understanding of high-g environment and ability to design and assess payload components and materials, including novel designs. Design and assessment of emerging technology MEMS based Fuses; Electronic Safety and Arming Units; and course correction technologies Understanding of terminal ballistics	Underpinning S+T
	Materials	Specialist steel forging and projectile manufacture Understanding of intermediate and high strain rate properties of materials. Generation and application of Equations of State and material models, including for novel lightweight composites.	Underpinning S+T
	IM Propulsion	Design, development and assessment of IM compliant gun charges Understanding of inter-relationship between charge and gun system, including influence on barrel wear, erosion and fatigue life. Design, development and assessment of IM compliant rocket motors on case specific basis. Internal ballistic modelling capability	Underpinning S+T
Explosives and demolitions		None additional to Energetic Systems requirements but see also Counter-terrorism chapter.	Will collaborate where best value for money
Pyrotechnic stores	IR and RF Countermeasures	Rapid design, development, assessment and manufacture capability for air platform expendable IR and RF decoys. Ability to assess obscurant systems for effectiveness and environment impact.	Underpinning S+T
		General Pyrotechnic Stores - None additional to Munition Systems requirements.	Will collaborate where best value for money

SAA, Medium and Heavy Calibre Munitions

B8.21 **Systems Integration.** The energetics content of systems and the harsh environment that they see, including gun; mortar: or other tube launch, mean that medium and heavy calibre Munitions represent a high potential hazard which needs to be mitigated by thoroughly validated design methodologies, good engineering practices and high quality manufacturing. The DIS identifies the need to retain onshore design authority status where UK is design authority for the relevant weapon system or platform but does not see retention of a large on-shore development capability as essential apart from the need to ensure the integration of UK designs into existing platforms and weapons. However, it is highly desirable that development is not unduly separated from design capabilities if those design capabilities are to remain credible. **The breadth and depth of Systems Integration and other technology activities taken forward in this area will be determined by a combination of joint teams implementing the DIS and DTS, and the requirements for Project MASS, (Munition Acquisition Supply Solution).**

B8.22 Unlike many other areas of defence equipment, many types of ammunition are produced in high volumes on dedicated manufacturing plant. This is particularly evident in the case of SAA. As such, the quality and performance attributes of the ammunition are defined by the manufacturing process as much as by the design. Thus, manufacturing technology is an important element of the strategy. The DIS also outlines that one route to substantially reducing whole life costs for medium/heavy calibre munitions is to hold lower munitions stocks, whilst retaining the capacity to replenish via surge manufacturing. This requires not only strong supply chain management by suppliers, but a robust munitions fill, assemble and pack capability onshore. Central to this are a rigorous quality assurance regime and skills, and confidence in the supply chain right through to components and materials, some of which will no longer be manufactured in the UK.

B8.23 Although potentially desirable to manufacture key components and raw materials onshore, it is no longer practical. The manufacture of explosive ingredients such as nitramines, where the UK has a long history of producing a high quality product, is no longer commercially viable. This situation is typical for a number of other material and component technologies (such as primary explosives and mechanical fuzes). Here UK systems integrators must use their world leading design skills and technological expertise to secure and assure access to those technologies from overseas partners. Likewise, **MOD will be proactive in using its collaborative links with other nations (most notably US and in Europe) in order to understand, influence, progress, and to secure access to future technologies that might not be commercially viable to manufacture in the UK, but which nevertheless are essential components of the systems vital to delivering operation capability.**

Weapon System Design and Development

World leading UK gun and ammunition design expertise has meant that high performance systems, such as the 120 mm rifled main armament on Challenger II (above), have been able to meet the specific and very demanding needs of UK tactical doctrine. This has led to many designs unique to UK. We will seek to harmonise our future weapon systems and ammunition requirements with those of allies in support of evolving doctrine, coalition operations and greater interoperability, whilst retaining the UK sovereign capability to integrate weapons systems and associated ammunition into our platforms.

In the short term we will sustain the gun technology expertise necessary to support intelligent customer status for non – UK designs, weapon integration, and through life management. We will also review the ability to design and develop new lightweight indirect fire gun systems in partnership with other nations in order to meet the needs of UK strategic and tactical doctrine.

B8.24 The UK has to be able to integrate and update munitions within its infrastructure. Increasingly, it also has to deal with material and component obsolescence. Coupled to the need to design for disposal or recycling, this indicates an open architecture approach might be beneficial, although at the present time it is not clear that it will be practical. **We will investigate this concept and the associated problems of certification with our suppliers..**

B8.25 Systems integration also highlights the importance of understanding the interface between the munition and the weapon. Since many General Munitions are gun or tube launched it is critical that there is a thorough understanding of internal ballistics; the influence of LOVA propellant charge designs or other IM propulsion; and operational limitations of the weapon / munition combination. Linked is the critical ability to design munitions to withstand the appropriate "g loadings" and to understand the limits of such designs. The ability to design "High g hardened" payloads, components and materials has benefited in recent years from advances in material modelling. **We will work with Industry and other government departments to sustain and where necessary enhance the UK's material modelling capability.** Critical to this is access to expertise and facilities in intermediate and high strain rate physics. We do not intend to invest specifically in code development: instead the emphasis is placed on the generation and application of constitutive material models. In the future, understanding the behaviour of novel composite materials is likely to be more important than conventional steels[5] if the concept of lightweight carrier rounds is taken forward (this is currently under investigation within the Research Programme). **It will also be important to understand external ballistics and how low cost guidance and course correction techniques might be implemented. This will be supported by MOD through ongoing research investment, and opportunities for European collaborative programmes will be explored.**

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[5] *The DIS states the need for a specialist steel projectile forging facility, subject to confirmation of value for money.*

Pyrotechnic Stores

B8.26 The pyrotechnics area is one where market forces still promote healthy competition without significant difficulties with security of supply. In general, MOD needs are likely to be met without an assured onshore capability. A notable exception is the case of advanced pyrotechnic or energetic expendable IR and RF decoys used to protect aircraft and helicopters from missile attack. In this case, a rapid response design and assessment capability is maintained in Dstl, with the capability to develop and manufacture in Industry. **We will sustain such an onshore capability, through the current arrangements.**

B8.27 A design and assessment capability for obscurant systems is maintained in Dstl. We are currently reviewing this area and may withdraw from the design aspects. An ability to assess the effectiveness and environmental impact of such systems remains a requirement.

General Explosive Stores and Demolitions

B8.28 The general explosive stores and demolitions category is also dominated by market forces, although anti-tank mine technology is being replaced by other area denial techniques and counter mobility technologies for future UK service use (see Close Combat chapter). Demolition stores are important in the Counter-terrorism context, but in most items in this overall category can be treated as commodities.

Priority Areas for Energetics Technologies

Table 3. Summary of Priority Technologies for Energetics Technologies

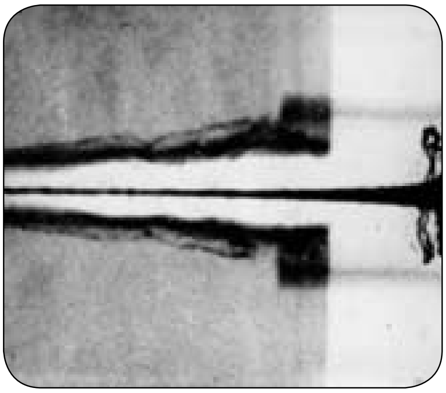
Category	Priority Technologies	National Capability Requirement	Potentially through collaboration
Energetics & Energetic Materials	Energetic Formulations suitable for IM compliant Munitions	Understanding of critical formulation and processing factors affecting safety, performance, life and environmental impact. Formulation and assessment for explosives and propellants. Design and development of LOVA Gun Propellants Development, Manufacture and filling of PBXs for specific Medium and Heavy Calibre Munitions. Development, Manufacture and filling of Elastomer Cast Double Base Propellants (EMCDB) and other propellants suitable for IM Rocket Motors (see Complex Weapons chapter)	Access to LOVA Gun Propellant manufacture through collaboration Access to other ingredients through collaboration. Underpinning S+T
	Smart initiation for IM Munitions	Understanding of critical design and manufacturing factors for Initiators, Igniters and Explosive Trains affecting safety, performance, life and environmental impact. Understanding the critical influence of initiation and ignition on system performance, including creation of multiple, scaleable or tunable effects. Design and assessment, including for micro-detonics and MEMs scale devices.	Collaboration to access non-UK materials and components. Underpinning S+T
	Modelling, Material Characterisation, Test and Evaluation.	Small-scale testing capability for assessing safety, life and performance. Interpretation of data and extrapolation to systems level. Rapid response small scale hazard assessment supporting forensics and counter-terrorism Integrated empirical / modelling approach Understanding novel energy release mechanisms and novel energetics.	Collaboration on underpinning S+T, including ignition and growth; detonics; high pressure combustion physics; access to hydro-codes; modelling and algorithm generation; reactive and multiphase flow; diagnostics and common standards

B8.29 Energetics technology is that associated with energetic materials (explosives, propellants and pyrotechnics), their applications and behaviour in components, sub-systems and systems. Energetic materials are perhaps the most critical component of general munitions since their behaviour has a key role in determining the performance, safety and life of a munition. They represent a technology which is also essential to the complex weapons area as well as niche applications in DAS; safety systems, such as power cartridges for aircrew ejector seat systems; and in Explosive Reactive Armours (ERA). The skills base in energetics technologies underpins other critical areas: Counter-terrorism and the Strategic Deterrent. Therefore our strategic approach to energetic materials technology encompasses those wider needs.

Electric armour defeating an RPG

B8.30 Energetic materials must not be viewed in isolation and thus many of the required energetic materials technologies and technical capabilities are embedded in the requirements for General Munitions and their direct counterparts in Complex Weapons. Emphasis is placed on the following energetics technologies:

- **The UK will retain the capability to understand the critical parameters of explosive and propellant formulations affecting safety, performance, life and environmental impact and extrapolate to systems level.** Specific development and manufacturing capabilities are specified in the DIS[6], subject to confirmation of value for money.



X-ray image of heat blast

- The ability to create precision, multiple, and scaleable effects will be derived in part from understanding of the role of initiation in tailoring the output of the warhead. In certain warheads, intelligent fuzing and Smart Initiation may be more important than any of the other component technologies. **We are directing research on initiators, igniters, and explosives trains to underpin these systems level effects, as well as traditional factors such as safety, life and environmental impact.**

- Access to new ingredients, particularly novel high energy density materials, novel energy release mechanisms, or those offering safety/environmental advantages. Access via a bulk-manufacturing route in the UK is unlikely to be viable. UK should use its synthetic chemistry, detonics, materials characterisation, formulation and other skills as leverage with international partners to access new technology, licensing UK intellectual property overseas where necessary. **MOD will facilitate such access using its research programme and collaborative links.**

- Materials characterisation, whether of raw ingredients or final formulation, coupled to predictive modelling and assessment capabilities remains a core skill to be sustained, and even enhanced. Hazard characterisation remains a high priority, and a continuing capability is required to support counter-terrorism and forensics operations. **MOD will work with other government departments to retain a rapid response hazard assessment capability.**

- There is a danger of energetics expertise falling below critical mass in both in UK and in Europe. **A current initiative between MOD Defence Ordnance Safety Group (DOSG), Cranfield University and the SEMPTA Skills Sector Council on "Training and Education in the Explosives Sector" will continue to receive MOD support.** The EU, through a Leonardo da Vinci programme, is seeking to follow the UK example by developing European standards and qualifications.

Future Technology Issues

B8.31 Future environmental legislation and public opinion has significant potential to impact this sector, with a consequent effect on training and ability to conduct operations. **The UK will continue to pursue the concept of "Green Munitions"7 in collaboration with other nations.**

B8.32 The scope for innovative new technology to influence the sector remains. Techniques, such as super-critical fluid or novel cryogenic processing, are likely to impact the feasibility of the recovery and recycling of munition components. **We will use the research programme to investigate the feasibility of "environmentally friendly" recover, recycle and re-use technologies.**

B8.33 MEMS technologies and micro-detonics as applied to Electronic Safety and Arming Units (ESAU) and fuzing are promising areas of innovation, as is MEMS-based guidance in course corrected projectiles. Intelligent fuzing is seen as a key enabler for precision effects in the future.

B8.34 **We will work with Industry, across the General Munitions and Complex Weapons sectors, to identify joint investment routes for intelligent fuzing concepts. We will also work with our international partners to ensure that existing fuzing standards do not act as an unnecessary barrier to the uptake of these innovative technologies.**

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[6] *Fill, assemble and pack; PBX manufacture; LOVA Propellant design and development.*

[7] *Munitions with minimal environmental impact.*

The Way Forward for General Munitions and Energetics Technologies

B8.35 Project MASS, which follows on from the MOD/BAE Systems FPA, represents the key strand in the way forward for the SAA, Medium and Heavy Calibre Munitions area. **Project MASS and the DIS General Munitions Implementation Team will work with Industry to confirm, by the end of 2006, that the national capabilities identified by the DIS can be delivered cost effectively, within the current budget.**

B8.36 MOD will work with suppliers through individual partnering arrangements, where they exist, to implement the Defence Technology Strategy. However, it is recognised no suitable collective forum exists for MOD research and acquisition customers to co-ordinate activities with multiple suppliers. Therefore, MOD will work with industry to establish a Technology Steering Group covering "General Munitions and Energetics Technology" to aid implementation of the DTS. It will develop Technology Roadmaps, Research Exploitation Plans and act as a central forum to identify opportunities for joint MOD/Industry research investment. This Group will maintain an overview of research activities and related industrial activity to ensure coherence, direction and aid early exploitation. Reporting lines will be jointly to the Munitions Management Board, Defence Ordnance Safety Board and to the NDIC R+T Sub-group.

B8.37 **MOD will contract the core National Energetics R+T programme, underpinning the General Munitions and Complex Weapons areas, within a single contractual framework to ensure coherence and visibility**. It is anticipated that the contract will be placed with a broad based consortium encompassing research suppliers, SMEs, universities and larger industry, early in 2007. This programme will be aimed at sustaining the research elements of the energetics technology capabilities and expertise identified in this chapter as well as technology de-risking activities. It will play a central role in providing the UK leverage required to access technology and knowledge from overseas through collaboration with International partners. The results of this programme will be exploited via the most appropriate route, including individual partnering arrangements where practical.

B8.38 **A National Defence Energetics Community (NDEC) will be formed to promote the generation, transference and sharing of the energetics skills, training and best practice.** This will cover all relevant defence interests (MOD, suppliers and academia) underpinning General Munitions, Complex Weapons, Counter-terrorism, Strategic Deterrent, and other applications. Within this multi-lateral forum we also aim to work with other government departments (Health and Safety Laboratory, Home Office, DTI and Research Councils) to ensure that the overall UK energetics skills needs are met.

Explosives trial

B9 Fixed Wing and UAVs

Introduction

B9.1 Fixed wing systems include combat, training, C4ISTAR, transport and tanker manned aircraft, as well as the broad spectrum of Unmanned Air Vehicles (UAVs). Manned combat platforms and unmanned systems will remain the focus of MOD's air-related technology planning and this chapter content reflects that position. Transport and tanker aircraft are largely treated as commodity items and as such require little direct MOD technology investment. A notable exception is the area of Defensive Aids technologies, which are applicable to all operational classes as well as rotorcraft (see Electronic Warfare sub-section, this chapter). Although combat aircraft will often be the primary initial recipients of many of the DTS technologies of interest, the Through Life Capability Management (TLCM) discussions at the end of this chapter are equally relevant to all classes of platform from large aircraft to trainers.

Typhoon

B9.2 The DIS articulates the challenges and paradoxes facing the aerospace sector today. In terms of importance to defence, fixed wing assets remain a critical component of military capability, with air power often the first force element to be employed in a conflict. The air power attributes of deployability, flexibility and agility are highly relevant to expeditionary warfare that is the focus of UK planning for the foreseeable future.

B9.3 The UK aerospace sector still exhibits significant design, manufacturing and technological expertise ranging from manned combat aircraft build and integration through key systems capabilities including propulsion, sensors, electronic warfare and emerging unmanned air vehicle technologies.

B9.4 The viability of the supply base is challenged by the continuation of historic trends including the reduction of fleet numbers and the consolidation of the numbers of in-service types. Technological advances allow us to maintain capability with fewer, more capable platforms and platform operation may now extend decades beyond the production line closure. The resulting discontinuity of demand and the limited opportunities to develop and exercise key system design skills challenge the maintenance of expertise in the supply base. The anticipated multi-decade operation of the Joint Strike Fighter and Typhoon has removed the requirement for the UK to design and build a future generation of manned fast jet aircraft for the foreseeable future[1]. Unless platforms are architecturally or contractually suited to the ready upgrade of capability, extended service lives can also limit the opportunities for integration of new technologies, impacting on Tier 2 and 3 suppliers.

B9.5 Furthermore, in too many cases the flexibility and agility of air power has not been matched by agility in major aerospace programmes. The time and cost of relatively modest platform upgrades has too often been hard to justify and air power risks pricing itself out of business.

B9.6 The DIS identifies the UAV as an emerging system in aerospace. Although there are powerful drivers for the employment of unmanned systems (see sub-section on UAVs), the development and employment of advanced combat capable UAVs clearly provides significant technical challenges. It also provides an opportunity for technological innovation to challenge the traditional economics of development, manufacture and employment of air systems.

Joint Strike Fighter with Carrier (BAES)

B9.7 We have embraced software to provide much platform functionality, with good reason, but this has come with a significant price. Our dependency on software has not been matched by an ability to 'own' software (to write, test, certify and modify) at a reasonable cost and time. In the case of UAVs, the functionality brought by the aircrew will have to be provided in the unmanned system either by introducing situational awareness and robust communications to remote controllers or by giving the UAV independent decision making capability – autonomy – which will introduce a

[1] *Fixed Wing Chapter, Paras B4.2, B4.19*

further dependency on Safety Critical Software (see UAV sub-section in this chapter, and Software sub-section in Cross Cutting Technologies).

B9.8 In previous eras, sovereignty was vested in the ability to deploy platforms with an adequate performance edge over the threat to be operationally effective. A performance edge was maintained, for example, by developing a more powerful engine for a fighter aircraft, or by introducing a new type into service. In the era of integrated systems and multi-decade service lives, sovereignty in air power is exercised via national control of the platform systems architecture and interfaces, in order to be able to effect the changes to mission systems at the rate that operational needs dictate.

B9.9 **The attainment of operational sovereignty in air power is via:**

- **Exercising national control of the platform systems architecture and interfaces**
- **Developing an intimate knowledge of threat weapon systems and possessing the means to deny them the ability to operate effectively**
- **Deploying cost–effective and affordable equipment solutions**

B9.10 These are tightly linked requirements, but unless the third is met, the first and second are irrelevant.

Priority Technology Areas

B9.11 Key sector technologies are discussed here under the categories of Platform Systems, Unmanned Air Systems, Mission Systems and Through Life Capability Management. The latter category covers technologies and technology management issues relevant to the affordable delivery and growth of capability throughout the service life of an air system. The summary table below gives details of the priority technologies and the areas where there is a need to retain national control; specific action points for each area are addressed in the sub-sections that follow the table.

Table 1. Summary of Priority Technologies

Priority Area	Priority Technology	National Capability Requirement	Potentially through collaboration
Platform Technologies			
Low Observability - Acceptance - Integrated systems - Through Life Management - Standards & traceability	Signature budgeting tools and processes Signature prediction tools Integrated design Cost analysis tools Signature measurement facilities IR & RF structural and coating materials Antennae and aperture Emissions management High tolerance manufacturing Mission planning	ICS for LO support solutions Integrated design development and cost–effectiveness assessment	
Propulsion - Through Life Capability Management - Novel systems	Health and Life Management Damage tolerant components Repair of high value assets Hot section durability Performance and life modelling Fan technologies e-HALE solar/battery integration	ICS for UAS propulsion ICS for TLCM enablers ICS and assured exploitation routes for TLCM enablers	Engine supportability
Aerodynamics, Structures and Control - Performance optimisation	Integrated aerodynamic Design toolsets for Rapid prototyping and assessment of vehicle dynamics & control systems	ICS for novel platforms and control solutions Design and systems expertise Technology watch for novel vehicle and flow control	
UAV - Small and novel UAV - Tactical UAV - High End UAS	Autonomy Rapid prototyping Sense and avoid SE concept development Lean manufacturing Enterprise and economic models	Indigenous capability autonomous UAV control Airworthiness/certification advice on autonomous systems Experimental UAV design development and assessment capability Influence on sense and avoid technologies and legislation Test and experimentation for UAV battlespace integration	Approaches to regulation of UAV operations in controlled airspace

Priority Area	Priority Technology	National Capability Requirement	Potentially through collaboration
Mission Systems			
Sensors - AESA Radar - EO Targeting	TR module High resolution large area SAR Radar beam forming and processing ATR Active illumination technologies	AESA design, test and manufacture National capability to develop and implement radar modes National ATR & database capability	
Mission Management - SA & Shared Situational Awareness - Real time tasking and deconfliction - Complex mission delivery - Coalition interoperability	Combat ID via SA Data fusion- platform & network Datalink utilisation Adaptive Decision Support Systems MMS interoperability & IERS	ICS for SSA enablers Experimental capability for datalink and network utilisation Integrated assessment for	
Electronic Warfare - Air Platform Protection - Offensive EW capabilities	Information database toolsets pyrotechnics Laser technologies MAW DAS architectures Electronic attack payloads NAVWAR Multifunction apertures RWR/ES NELS Hostile Fire Indication	Deep understanding of threats National control of DAS architecture and interfaces National ability to programme EW systems ICS for all aspects Design Authority MAW Independent programming ES EA technologies and DA for integrated and compact payloads Rapid exploitation of countermeasures	
Through Life Capability Management			
System & Avionics Architectures - Standards - Certification - Open Systems	High throughput , deterministic databus technologies Flexible scheduling Modular safety case Modular & incremental certification	ICS for Open standards	Technical and economic implications of databus standards Assess and develop emulation solutions for UK military avionics hardware
Obsolescence	COTS based Emulation technologies	ICS for obsolescence solutions	
Weapons Integration	Plug and play architectures Aerodynamic prediction tools	Indigenous capability for weapon integration	Weapons integration enabling technoloies

Platform Technologies

B9.12 The role of the platform is to deliver weapon systems and sensors to the right point in the air battlespace to ensure tactical advantage. This sub-section identifies our needs for key technologies that will enable platforms to operate cost-effectively within the modern battlespace.

Low Observable (LO) Technologies

B9.13 A low probability of detection and engagement is likely to be important for the survival of future air assets in the presence of advanced air defences. LO technologies enable survivability by reducing and maintaining at a low level radar and electro-optical signatures, either to minimise the chances of detection or to enhance the performance of platform EW and self protection systems. LO technologies encompass the means to:

- Understand signature requirements to meet operational needs given future threat trends;
- Design and manufacture affordable air vehicles with signatures at operationally significant levels;
- Monitor and maintain such signatures in-service;
- Support the optimal operational use of LO air vehicles.

The primary drivers for UK fixed wing LO technology development are the ability to provide national through-life support to LO air vehicles, including embarked operations, and to support any decision to undertake full or partial UK-led development of an LO Unmanned Air System (UAS).

B9.14 The capability to design, build and deploy LO platforms is based on integrating a portfolio of technologies including:

- Understanding of threat air defence system performance;
- Operational analysis (OA), signature budgeting tools and processes;
- Signature prediction tools based on a detailed understanding of RF and IR electromagnetic phenomenology;
- A range of IR and RF signature measurement facilities from laboratory and spot measurement to full vehicle ground and air measurement;

- Materials, including IR and RF structural absorbing materials, surface coatings and hot end materials;
- Signature control solutions for principal sources, including overall vehicle configuration, communications antennae, sensor apertures, and propulsion system;
- Whole vehicle integration techniques;
- High tolerance manufacturing capabilities;
- In-service measurement, support and repair facilities and techniques;
- LO mission planning and management.

B9.15 Much of fixed wing LO capability in the areas of threat understanding, OA, LO design and budgeting methods, signature assessment tools and facilities, materials and mission planning systems is also applicable to Complex Weapons.

B9.16 **UK Capability** LO Technology is an important area where collaboration is difficult owing to reluctance to share sensitive information. Given this constraint we require the ability to develop LO requirements and maintain a strong Intelligent Customer capability. Significant relevant capability now exists across the UK technology and manufacturing base. The UK is world class in several aspects of LO technology including high tolerance manufacturing, as a result of previous demonstrator activities including the REPLICA programme in the 1990s.

B9.17 **LO Technology Development** To support the developing UK requirement for national through-life support for LO air vehicles and in order to consider the full or partial UK-led development of an LO UAS, we require access to industrial design and systems engineering expertise and to innovative research technologies. We will therefore continue to invest in key elements of the portfolio of signature control technologies discussed above, recognising the need to approach signature control from a whole vehicle, integrated system, perspective.

B9.18 If the UK makes a decision to develop an indigenous LO UAS, the ability to fully understand the interrelationship between signature goals, survivability, mission effectiveness and whole life costs will be crucial.

B9.19 **Through Life Support** LO Support Capability refers to the key technologies, equipment and processes necessary to assess and manage air vehicle signatures in service, both by front line units and following maintenance repair and upgrade. At a minimum, the UK needs:

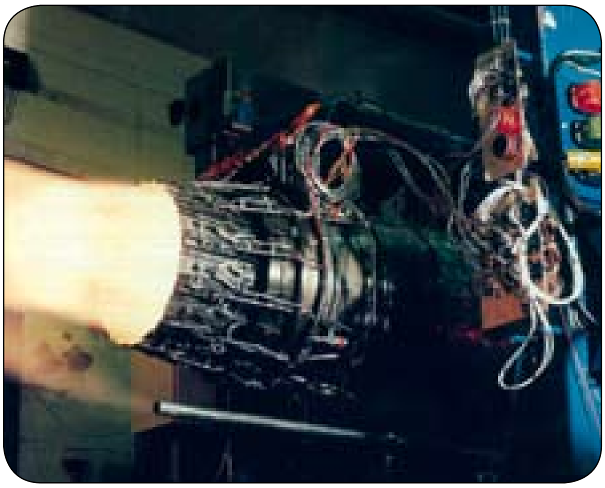
- Full understanding of the risks, limitations and operating implications of LO support solutions to act as an Intelligent Customer (MOD) or Supplier (Industry);
- A coherent LO 'ownership policy', which covers contractual acceptance of LO platforms and support systems; through life signature measurement and maintenance facilities and processes.

B9.20 As part of this ownership policy, a rigorous audit trail between measurement facilities in government and industry back to national or international signature measurement standards needs to be established, in order to support the contractual acceptance of LO components and platforms.

B9.21 **In order to continue to develop the UK's capability in LO platforms and through life support, we will:**
- **Consider a technology demonstrator programme to attain intelligent customer status for LO support solutions;**
- **Continue research and development of advanced underpinning LO technologies;**
- **Work towards implementation of a national LO measurements and standards policy.**

Propulsion and Power Systems

B9.22 **Overview** Propulsion and power systems are a major contributor to platform whole life costs and platform availability is highly dependent on reliable propulsion systems. MOD therefore needs to retain the necessary national capability to efficiently sustain its current and planned fixed wing propulsion systems, and also needs to ensure it has the necessary supply base for future upgrade options. Targeted investment needs to be directed towards critical propulsion and power technologies to ensure both a strategic influence and a viable source for key capability-enabling propulsion technologies.



EJ200 jet engine full re-heat

B9.23 **Technology priorities** MOD currently spends in the region of £200M per annum supporting its aero engine fleet. Our strategy is to understand the key cost drivers in order to identify technologies that can reduce support costs, whilst ensuring that the potential support savings are balanced against implementation cost and risk. **We will give investment priority towards readily exploitable high-gain technologies (see table below). This must focus on those areas where industry is not incentivised to fund the work, but must take civil developments and investment into account.**

Propulsion Sustainability: Desired Capabilities and Characteristics	Sustainability Technologies
Engine Health Management	High temperature sensors, data fusion, health prediction algorithms
Object Damage Tolerance	Surface treatments
Life Management	Active life prediction techniques
Hot Section durability	Thermal barrier coatings
Repair of high value assets	Repair of Bladed Rings and Bladed Disks
Engine controls	Tuned performance models

B9.24 Current research focuses primarily on engine health management. With the introduction of Typhoon/EJ200 and later JCA, we anticipate that new areas will begin to emerge as cost-of-ownership drivers, and associated research gaps will need to be filled through redirection of aero engine supportability research. With many nations facing similar fleet sustainment challenges as MOD, and moving towards similar contractor support arrangements, this is seen as an area in which international research collaboration (IRC) can augment MOD knowledge and practices, although we need to ensure that sustainment technologies are exploitable through the Original Equipment Manufacturer (OEM).

B9.25 MOD will continue to invest in underpinning technology development, particularly for JCA through-life capability assurance.

B9.26 **Our position is not to invest in hot section technologies for new build or higher performance engines. However, we will consider technologies for WLC reduction. We will consider participation in the AeIGT[2] Environmentally Friendly Engine demonstrator, currently funded by DTI and industry, in order to further derisk hot section sustainment technologies.**

B9.27 For UAVs and UCAVs, the key strategic technologies are associated with vehicle integration. Continued technology maturation for inlets and exhausts is essential to assure a strategic position for future system development opportunities. MOD also needs to develop intelligent customer status on affordability/capability trades for UCAV engine options ranging from off-the-shelf to new build. However, any significant investment in UAV propulsion will be judged against likely fleet sizes for the foreseeable future.

B9.28 **Novel Propulsion** Significant progress has been made under the industry and MOD funded Zephyr lightweight electric High Altitude Long Endurance (eHALE) UAV in the field of high performance electric propulsion. We anticipate that further development of individual battery and lightweight solar cell technologies will be progressed primarily through commercial investment, and that further MOD investment would be in eHALE propulsion system integration refined through experimental application.

B9.29 **For fixed wing propulsion, we will work with the supply base to develop exploitable technologies to improve the through life management of the MOD's propulsion systems.**

Aerodynamics and Structures

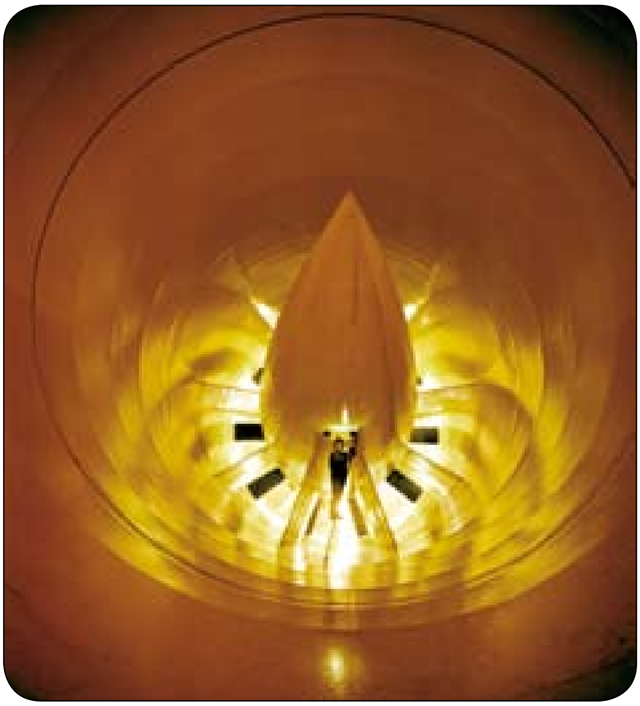
B9.30 Advances in aerodynamics and structures are primarily led by the civil aerospace sector, where the significant economic drivers are to achieve improved performance, lower fuel burn, reduced noise and reduced weight. All of these are key to the civil sector meeting the targets identified within the ACARE 2020 vision for air transport[3] .

[2] *Aerospace Innovation and Growth Team – National Aerospace Technology Strategy Implementation Report, 2004.*
[3] *Advisory Council for Aeronautical Research in Europe- Strategic Research Agenda 2002, establishes sector goals to reduce the environmental impact of aviation – see www.acare4europe.com*

B9.31 Military drivers for aerodynamic and structures development and expertise include the need to achieve:

- Intelligent customer status (ICS) for novel planforms and control solutions driven by signature considerations
- ICS for aspects of integration with aerodynamic components, including propulsion integration and IR signature prediction
- ICS for novel structures and composite materials, including through life ownership and damage tolerance
- ICS for internal weapons carriage and release solutions (see also TLCM sub-section, Weapons Integration)

B9.32 **Technology Issues** Where there is potential for significant gain is in the discipline of the integration of technologies. The capability to optimise external shape and internal structure for a variety of objective functions (depending upon the role or mission) could have significant impact not only on the performance of the platform but also responsiveness of the system to changes of requirement and more rapid deployment of new technology.



Wind tunnel fan

B9.33 While the interaction between aerodynamics and structures is obvious, the development of true integration environments would have wide reaching implications across all technologies. As well as addressing current areas of interest including the combined propulsion, structural and external flowfield contributions to IR signatures, new innovative developments that imply significant impact on the 'fabric' of the overall system could be rapidly evaluated, integrated and deployed.

B9.34 Innovative technologies areas of interest include:
- Onboard wireless communication
- Flow control
- MEMS
- Energy harvesting
- Actively damped structures
- Novel flight control systems
- Structural electrical energy storage
- Improved power management through fully integrated propulsion
- Active load control

B9.35 Many of these potential high-payoff topics are currently speculative **and can be effectively addressed through a strong university research base. The key to progress will be via addressing the integration of these technologies within candidate systems, both in multidisciplinary design tools and in experimental systems at the earliest stages of development. We will work with Universities and industry to identify and understand the integration impact of high-risk high-payoff aerodynamic, structural and control technologies.**

The Unmanned Air Vehicle and System

B9.36 The unmanned air vehicle or UAV, is now increasingly referred to as the unmanned air system (UAS)[4] to reinforce the concept that the platform is just one component of the wider integrated system, including payload and sensors, but particularly the communications and control environment within which the platform has to be integrated.

Watchkeeper landing at ParcAberporth (Thales)

[4] For the purposes of differentiation this document uses the descriptor ' UAS' for sophisticated, high performance, large payload or combat capable unmanned systems, and UAV for medium sized, tactical sensor platforms or smaller

B9.37 The UAS provides new opportunities for the delivery of military capability, by addressing some of the limitations of manned platforms and provides an opportunity to challenge the conventional economics and timescales of air power development and delivery. The UAS also provides significant technical challenges, primarily in integration in the battlespace and in the development and certification of autonomous systems.

B9.38 Unmanned platforms and concepts can be crudely categorised into three bands:

- **Unmanned Air System**: direct analogues of manned systems, with equivalent performance levels, such as unmanned combat air systems (UCAS) or large payload long range ISR systems;
- **Medium sized systems**: including tactical sensor platforms such as Predator and Watchkeeper which are physically smaller than a manned equivalent and typically have manned light aircraft levels of performance;
- **Small systems**: including man portable and micro air vehicles (MAV) which will have applications in close combat and urban operations as they become practical.

The Positioning of Unmanned Air Systems

B9.39 The UAS is unlikely to displace manned types for the lives of Typhoon and JCA. Any UAS introduced over the next 15 years or so will therefore co-exist alongside manned tactical aviation for decades. Any UAS procurement would also introduce an additional type into service. It is therefore clear that the arguments for introducing an unmanned system have to be based on delivering a complementary capability to manned platforms– the UAS case has to be argued from the standpoint of clearly delivering capabilities that manned platforms cannot.

Zephyr, solar powered unmanned air vehicle

B9.40 This is true for:

- **Persistence** A UAV could stay on station for much longer than a manned aircraft, for high altitude operations to support extended sensor or comms footprints;
- **Expendability** For high threat and hostile (e.g. CBRN) environments;
- **Signature reduction** The UAV offers the ability to get nearer to design shapes that are more purely optimised for signature reduction, and smaller physical size will be of some benefit. However lower airframe signatures will still have to be matched by lower sensor and antennae signatures.

B9.41 We do not envisage unmanned aircraft being developed for air combat missions for the foreseeable future, as Typhoon is providing a dominant air defence capability. The UAS design focus will be for stealthy platforms with modest manoeuvre performance although endurance and altitude capability will be emphasised in ISR designs.

UK Capability – UAS and Tactical UAVs

B9.42 The UK is world class in several aspects of UAS/UAV technology and systems development, including the areas of sensor payloads and synthetic environment based operational concept development. Through procurements such as the Watchkeeper tactical ISTAR UAV programme, and through a structured series of demonstrator programmes, the UK is progressively raising its capability to assess and develop integrated total unmanned system concepts, including autonomous operation for future UAS systems.

Smaller and Novel Systems

B9.43 The UK has a niche capability in lightweight electric High Altitude Long Endurance (eHALE) UAVs (see also Propulsion) that offers the potential of persistent sensing and communications relay at a fraction of the cost of conventional systems. The Zephyr eHALE UAV has demonstrated how an integrated design approach to structures, materials, energy sources and sensors can lead to a potentially new class of system.

B9.44 Smaller vehicles and innovative systems can also be developed and operated by small companies harnessing the creativity and innovation to be found in them. The UK SME base has significant small and subscale platform rapid prototyping skills, including accelerated flight dynamics and control development. As for all scales of UAV, individual technologies should not be pursued in isolation and responsive multidisciplinary teams are needed to

develop successful innovative systems. SMEs[5] are well placed to act dynamically in this area, although we do not underestimate the finance and infrastructure often needed to transition from innovation to delivery of an operational system. W**e will engage with the supply base, including the SEAS DTC, to identify concepts and routes to service to deliver air capability using innovative unmanned systems.**

Autonomy

B9.45 Removing the embedded pilot requires back-filling the human control contribution. This could be achieved by enhancing the sensor suite and providing high bandwidth data relays to give a remote operator the same level of situational awareness as the embedded pilot. However this is not seen as a practical or robust solution for combat missions. Complex and dynamic missions will be achieved by granting the UAS autonomy in terms of situational awareness, tactical analysis and decision making.

B9.46 Autonomous UAS control systems will maximise the effective tactical employment of the unmanned platform. Using on and off board sensors to gain situational awareness of the local battlespace and tactical picture, the autonomous system will then prioritise the vehicle actions taking into account weapon and fuel states, target priorities and deconfliction with other air operations.

B9.47 For the foreseeable future, a remote human operator will remain in the loop, overseeing the unmanned system and positively controlling at key stages such as weapon release. The operator may be in a ground station, large aircraft or tactical jet. Autonomous control technology will be embedded in the UAS platform, but also above the platform level in the control chain - related decision support systems will aid the human controller in tasking multiple UAVs in dynamic tactical situations (see Mission Management sub-section).

B9.48 There are several technologies that can deliver autonomy, including software agents, machine learning techniques and knowledge based systems. Fundamentally, the adoption of autonomy implies putting more safety critical software into the platform, which itself will need clearance and through life sustainment. **We will continue our investment in sophisticated UAS control, taking autonomy through to demonstration, initially using manned surrogate platforms to derisk in representative environments before migrating to unmanned systems**

Payload and Integration

B9.49 With the exception of autonomy, there are few individual technologies that are specific to UAVs, the emphasis being on successful integration of technologies within compact and power efficient payloads. Sophisticated low observable platforms will need sensor and communications aperture and antennae signatures compatible with the overall vehicle signature goals. High bandwidth compact communications and radar ESM systems are needed for small-medium UAVs, as are effective networked emitter location systems (NELS). The small–medium tactical UAV also provides opportunity to employ unusual payloads that would be aerodynamically difficult to integrate with fast jets, including foliage penetrating radar (see also C4ISTAR chapter and Radar, Cross Cutting Technologies chapters).

Data Management

B9.50 A challenge remains in the management of the data and intelligence collected within the UAV ISTAR system. The management of the collection, exploitation and dissemination function will need to be coordinated to employ best the resources available, including assets, manpower and bandwidth. Technologies to assist in the management of these will be important, including optical communications for high bandwidth, point to point relays. For wider ISTAR applications, it is likely that real-time analysis of imagery will be required and supported by dynamic control of the transmitted image resolution and content.

Automatic Target Recognition (ATR)

B9.51 The need to analyse and manage large quantities of imagery generated by airborne sensors will result in ATR becoming a critical component of the overall strike and ISR UAS capability. ATR systems will be positioned at various points in the mission and intelligence cycle, acting as filters to overcome bottlenecks created by finite communications capacity or the finite ability of the human to analyse large quantities of imagery for possible embedded targets. A future strike UAS would never launch a weapon without recourse to a human decision maker; the platform will relay back ATR-prefiltered 'probable target' images to the off board mission controller, for confirmation or rejection by the human in the loop before potential engagement.

[5] *or small independent units within larger companies*

Systems Integration

B9.52 We identify technology risk for Unmanned Air Systems lying primarily in integration at all system levels, including:

- Integration of autonomy with operational flight program software
  - Certification, change management
- Integration of UAS with manned platforms
  - Control of multiple UAVs
- Safe integration with airspace high tempo manned tactical operations
  - Operating in close proximity to manned platforms (or other UAVs), including autonomous air to air refuelling
  - Safe conduct in airspace and on airfields, including sense and avoid technologies

B9.53 Integrating UAVs into the manned battlespace is occurring today through procedural deconfliction, though this does not allow best use of the airspace. Positive deconfliction through the development of sense and avoid technologies, will allow manned and unmanned systems to share the same airspace. Commonality of air traffic standards, and technologies will also be essential. **We will monitor commercial and international projects in the area of sense and avoid, and will consider involvement in collaborative activity in order to promote approaches to regulation of UAV operations in controlled airspace**

UAS Technology and Capability Growth Management

B9.54 Inevitably for such novel systems, as operational experience grows, the concepts of operation will be modified and refined which will dictate changes or additions to the UAS capability. This will be driven by a willingness to conduct more complex operations as UAVs prove themselves, and by the growing connectivity with other platforms and systems in the battlespace within the overall Network Enabled Capability. This implies a spiral development and staged operational employment programme, with coherent technology management and capability growth plans.

B9.55 This will require flexibility in terms of procurement processes, sustained investment in generations of experimental systems, and dynamic and responsive joint industry/government project teams. A key technological aspect is that the system architecture has to be adaptable to support growth without requiring full system recertification at every change increment. If the architecture is inflexible, does not have growth potential, or is not incrementally certifiable, the UAS will not deliver its promise.

Economics of UAS ownership

B9.56 Any UAS procurement for the foreseeable future is likely to be at modest fleet sizes compared with current manned fleets. Attributes such as longer persistence would reduce the fleet size further, with need for fewer vehicles to provide round-the-clock sensor coverage. Other trends, such as the increasing employment of synthetic environments for training and mission rehearsal, cut live operating costs but again further reduce the need for platform numbers.

B9.57 Innovation in development, manufacture and ownership is therefore needed to move away from economic models based on large unit production runs. This 'economic breakthrough' will be founded on the transition of rapid prototyping techniques into rapid capability provision, with receptive system architectures allowing the progressive growth of that capability through planned incremental acquisition and reactive evolutionary development.

B9.58 This emphasises technologies that can impact on through life economics including platform materials, rapid engineering processes, modular design methodologies and constructional developments. This could be developed to the point where the hull is more likely to be treated as a replaceable or shorter life component. **We will improve our understanding of how to specify requirements for through life flexibility and adaptability, and where the over-specification of requirements of performance and signature goals could distort whole life costs.**

Role Convergence and System Reuse

B9.59 The economic case for unmanned system adoption will be further strengthened where platform avionics and command and information management architectures are flexible enough to support a number of capability requirements by hosting new technologies. The reuse of core elements of modular systems across role-tailored platform variants will also maximise return on non-recurring development expenditure. Flexible architectures and modular designs therefore to be considered in our understanding of the opportunities for role and requirement convergence and design flexibility. **We will coherently consider UAS role convergence, such as the synergies between deep strike sensor needs and emerging persistent ISR requirements, and will work with industry to identify the employment of common core architectural and modular platform solutions to support different missions wherever possible.**

B9.60 **We will work with the supply base to develop and refine through life models of UAV ownership, validated by successive platform and mission demonstrators. We will target the appropriate system lifecycles to cost –effectively develop, refresh and grow capability as operational experience and need increases.**

Mission Systems

Sensors

B9.61 **Radar** Radar will remain the primary sensor for fixed wing platforms, providing surveillance, tracking, identification and fire control capability in all weathers. The active electronically scanned array (AESA) radar is the most significant mission system development in fixed wing air power, both for combat and ISTAR platforms, providing battle winning capability and the ability to switch roles between air-to-air and air-to-ground as the battlespace dictates.

Captor Active Electronically Scanned Array Radar on BAC1-11 (Selex)

B9.62 Internationally, the F/A-18E/F Super Hornet and F-15C are receiving AESA upgrades and France has recently cut Rafale orders in order to release funds for AESA development in order to sustain competitiveness in the export market.

B9.63 The instantaneous inertialess scanning and enhanced signal-to-noise performance in the AESA radar receiver circuit chain allow the formation of high quality tracks at ranges substantially greater than mechanically scanned systems. This enhanced situational awareness will allow multiple targets to be engaged over a much greater volume of air space, acting as a force multiplier. Synthetic Aperture Radar (SAR) and Ground Moving Target Indication (GMTI) modes provide the ability to image and track targets at high resolution through cloud and at significant stand off ranges and will bring ISTAR capabilities to front line tactical aircraft.

B9.64 The transition of radars to all solid state digital systems will significantly reduce whole life costs[6] . The ability to digitally reconfigure beam profiles and waveforms, store and manipulate data will allow radar apertures to share functions with other aircraft systems including communications.

B9.65 **UK Capability** The UK is world class in many aspects of combat radar systems and has a breadth of industrial and technological capability within the Radar Tower of Excellence companies ranging from system primes through to key GaAs component providers and RF design and signal processing houses. To ensure the future air component can maintain a dominant position, the UK needs to retain the ability to develop, test and produce combat aircraft and ISR radar. This capability needs to be secured within industry by continuity of radar technology development whilst using platform and system upgrades and technology insertions in order to maintain an operational edge and industrial competitiveness. We will continue to work with the supply base in the planning of R&D in order to further align MOD and PV spend in Fixed Wing radar systems.

B9.66 **AESA technology development** We will build on the AMSAR TDP within international programmes aimed at de-risking Typhoon AESA adoption and concentrating on advanced beam forming and air to air modes. The UK has also used the expertise gained via the AMSAR TDP to build and integrate a highly air to ground capable AESA within a standard Tornado GR4. Integrating an experimental system within a front line aircraft represents a new approach to accelerating technology development and demonstration by allowing the technologies to be exercised in a realistic environment, providing rapid feedback from users. It also derisks integration within the intended host platform, ahead of a full-scale development programme. This Advanced Radar Targeting System (ARTS) is being considered by MOD as the basis for a limited fleet adoption to sustain the GR4's all weather targeting capability.

B9.67 **We plan to use the ARTS experimental system as the recipient for subsequent development spirals by integrating more research technologies as they mature, including high performance SAR, ATR, radar mode management, and Man Machine Interface developments, to ensure that operators can effectively interact with sensor technologies to maximise SA and operational effectiveness.**

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[6] *A 10-fold increase in Mean Time Between Failure (MTBF) is anticipated which would revolutionise through life support and deployed logistic footprints*

B9.68 **Electro-optic targeting** The UK has world class capability in EO targeting sub systems and key components, demonstrated by the adoption of UK lasers in the US F-35 (JSF) and Sniper targeting systems. MOD and industry PV funded research has produced high performance range-gated solid state detectors and ruggedised compact lasers which are being combined within active or burst illumination laser imaging (BIL) systems, a key element of 4th generation targeting systems. These are showing significant promise for extended range and counter camouflage operations. The high definition imagery provided by BIL is also optimal to support automatic target recognition (ATR) systems.

B9.69 The UK currently enjoys a lead over the rest of the world in active illumination technology but recognises that this will be rapidly eroded without continued development. **The MOD is therefore investing in further developments including very narrow range gate detector technologies to refine 3D ground target images. We will now consider combining BIL with ATR processing within a fast jet and UAV demonstration environment in order to allow refine optimum modes of employment and evaluate options to integrate advanced EO targeting within a networked environment.**

B9.70 **Infra-Red Search and Track** IRST systems can be regarded as passive infra-red 'radars', exemplified by the Pirate system on Typhoon which has given the UK a leading edge capability in the airborne IRST arena. Processing is a particular strength, but may need to be further supported to retain this lead. The low installed signature contribution to manned and unmanned platforms, the high levels of angular resolution and potential contribution to ATR through imaging as well processing underscores the value to current and future capability when employed in a multi-spectrum fusion with RF sensors. **We will consider how best to maintain an indigenous capability to develop and exploit the signal processing of IRST systems.**

B9.71 **ATR** Automatic Target Recognition technologies are key to the future employment of radar and electro-optic imaging sensor systems. Advanced modes, waveforms and target recognition capabilities are treated as nationally sensitive. In many cases, they cannot simply be introduced into commodity sensor systems. There is a major need to preserve and develop the UK indigenous sensor capability at the system or sub system level.

Infra-red image of Chinook

B9.72 **Advanced sensor technologies** (see also C4ISTAR sector chapter) Difficult targets, employing camouflage, concealment and deception, still pose significant challenge for target detection and identification systems. Advanced sensor types such as hyperspectral sensors have not reached maturity for the fast jet environment (although active hyperspectral systems should be progressed to assess their suitability for air operations).

B9.73 We believe the time has to come to address whether a holistic sensing capability, using multiple sensor types distributed across a network of platforms, would be more effective in detection and ID of difficult targets than single sensor solutions. **To address networked heterogeneous sensor management, MOD will work with the supply base to address how best to coordinate the EMRS DTC, DIF DTC and MOD's applied research investment to progress multidisciplinary research in this area.**

B9.74 **Enabling Technology** A critical enabling technology for advanced sensors and sensor integration is precision inertial measurement units (IMU), where the UK needs to ensure access to suitable technologies to meet future needs. Current IMUs are sourced from the US, although there is some capability within Europe.

B9.75 **We will work with the supply base continue to capitalise on the UK's world class excellence in sensor technology, with an increasing emphasis on the attributes needed for the networked battlespace: multifunctionality and target recognition. We will undertake R&D with early integration of experimental technologies in representative operational systems and environments in order to more rapidly translate technology into front line capability**

Mission Management

B9.76 Mission management systems (MMS) provide platform operators with the real time information needed to conduct complex missions in a dynamically evolving battlespace. An effective MMS will have the following characteristics or functions:

- Creation of the tactical picture
- Presentation of that picture to the operator with clarity and prioritisation to maximise situational awareness (SA)
- Control interfaces to maximise efficiency for the interaction between operator and systems
- Calculation of optimal tactical employment of platform, sensors and weapons.
- Provision of decision support aids generating dynamic tactical advice
- Underpinned by geospatial data and frames of reference

B9.77 MMSs are receiving increasing attention as we consider the evolution of complex missions including attacks against Integrated Air Defences and pop up threats which need the dynamic spatial and temporal coordination of multiple assets and effects. The assets themselves may be a flight of UAVs, under the control of an operator in a fast jet, who has to manage and task the unmanned systems to best tactical effect. An effective MMS, with optimised man machine interfaces (MMI) and embodying decision support aids will be necessary to allow the operator to manage the complexity of this scenario.

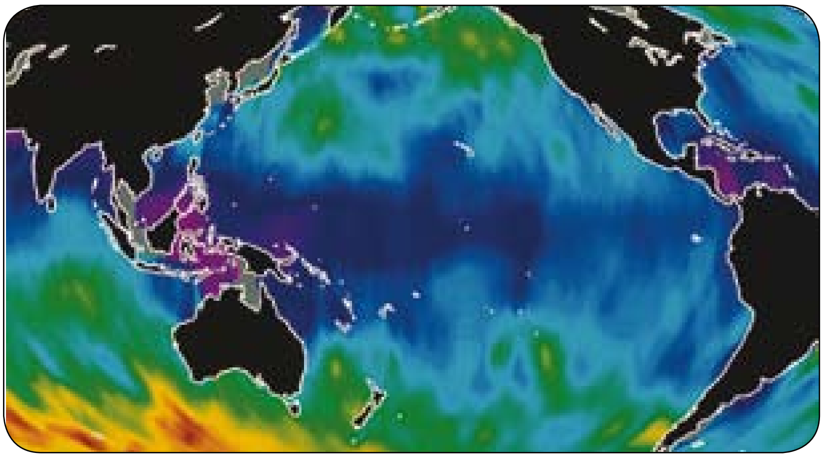
B9.78 **Tactical Picture Synthesis and Display** The tactical picture is created from the fusion of the pre-mission plan with data from on- and off-board sensors. This will include the distribution, sharing and fusion of ground and air target detections and tracks, target identities from ATR systems and incorporation of electronic surveillance (ES) data into the dynamically revised threat electronic order of battle. The tactical picture will be presented to the operator either through intelligent displays incorporating decision support aids or as real world overlays in Helmet Mounted Displays (HMD) and Night Vision Goggles (NVGs).

A modern "glass" cockpit (Typhoon)

B9.79 **Tactical Networked Operations** (see also C4ISTAR chapter for discussion of the wider NEC context) In order to allow tactical platforms to access and provide networked data as part of the implementation of Network Enabled Capability, the UK is mandating the use of J-Series messages on the Link –16 network and the Improved Data Modem (IDM) intraflight link. Practical and spectrum access considerations limit the opportunities to consider high bandwidth data links for fixed wing applications although effective employment of Link-16 and IDM could potentially link all tactical and strategic assets. **We will undertake further practical research and experimentation to refine how these bearers can best be used to support the coordination of strategic and tactical platforms and sensors in order to facilitate dynamic multi platform and time critical missions.**

B9.80 The use of machine translation technologies and the development of MMS common Information Exchange Requirements (IERs) will promote interoperability between coalition forces and between dissimilar platforms, allowing tactical plans to be developed, refined and deconflicted during a mission. The development of translation gateways will furthermore allow data sharing between air and ground forces' communications networks. The enhanced situational awareness gained by sharing trans-network data will greatly improve the quality of the tactical picture and support enhanced Combat ID (see below).

B9.81 **UK Capability** The UK is strong in the area of Mission Management Research but needs better coordination between research and technology providers and platform primes in order to maximise exploitation and integrate the multiple strands of mission management. **We will continue to develop our capability to undertake synthetic and live experimentation in order to accelerate the implementation of NEC in the tactical air operations.**



Modelling of global conditions

B9.82 **Enabling Technology** Geospatial Database Many cockpit displays and avionics rely on access to geospatial data, resulting in a plethora of disparate and equipment-specific data formats. **We will consider the cost effectiveness of the progressive adoption of common geospatial data solutions, including the Common Geographic Database Architecture (CGDA), across UK platforms and Mission Planning Systems in order to recognise through life savings on database maintenance and support.**

B9.83 **Combat ID** The need to minimise collateral damage and fratricide in targeting operations is a key driver. To complement the various active or transponder based schemes under consideration we will work to strengthen our understanding of the role of enhanced Situational Awareness (SA) in promoting Combat ID.

B9.84 **We will continue to develop synthetic and live experimentation capabilities to rapidly harness information and mission management technologies for the effective delivery of future air power in the networked battlespace.**

Electronic Warfare

B9.85 Access to, and control of the electromagnetic spectrum is vital to the delivery of air power in order to:

- Allow platforms to survive in threat environments by countering systems such as Surface-to-Air and Air-to-Air Missiles
- Overcome attempts to jam the operation of sensors, weapons and navigation equipment
- Utilise threat emissions in order to identify and locate a threat, either for avoidance or targeting

B9.86 As threat systems continually evolve and new and potentially unanticipated threats can be encountered in operations, the ability to rapidly modify EW techniques and equipment is vital. The UK needs to retain the national capability to implement countermeasures techniques and upgrade EW capabilities as operational needs dictate. Whilst this is possible with foreign sourced equipment, the national sensitivity of EW technologies and techniques can bring difficulty in modifying systems. Although not precluding the purchase of foreign systems, the Through Life Capability Management and operational support implications of fielded EW systems have to be considered thoroughly in any procurement.

B9.87 **EW Systems** Relevant EW technologies and systems broadly comprise sensors to detect the threat, including Electronic Support Measures (ESM) and Missile Approach Warners (MAW); techniques and technologies to counter threats, such as onboard jammers and towed radar decoys (TRDs) and expendable countermeasures including pyrotechnic flares.

B9.88 As threat missiles are cued or guided by radar or EO/IR sensors, air EW systems primarily operate in these bands, which themselves are also those used by many other onboard sensors such as radars. EW sub-systems are often integrated in Defensive Aids Suites (DAS) that coordinate the functions of an integrated EW system. We anticipate that further progressive integration will eventually combine EW and primary platform sensor functions. **Our goal is to progressively combine the functionality of traditionally separate sub-systems through the adoption of multifunction apertures, shared processing and configurable architectures.**

B9.89 UK Platforms have been procured with different EW system fits, with the result that there are numerous variants of EW equipment in service, driving up support costs. **Where possible we will move towards common EW system solutions for the fixed and rotary wing fleets to rationalise support.**

B9.90 The operational employment of EW relies upon the capture of threat system emissions using electronic intelligence (ELINT), collating the information in support databases that are then used by the programming software for EW systems. The ability to interpret emissions data, to understand threat system functions and to programme EW equipment is a UK military asset backed by significant levels of technical capability within the government and industry R&D base. **We need to develop solutions that improve the timeliness, accuracy and consistency of the tools and processes used to support programming of EW systems.**

B9.91 **RF EW Systems** Proliferating long range radar guided missiles exploiting communications networks, digital electronics and high speed processing are the main drivers for Fixed Wing RF EW capability and its constituent technologies. The key goals in this field are compact integrated sensor and effects payloads for airborne platforms; and ISTAR class geolocation and ID from tactical fixed wing and UAV assets.

B9.92 Radar Warning Receivers (RWR) warn of engagement by missiles allowing platforms to deploy chaff and activate on–board countermeasures or off-board Towed Radar Decoys (TRDs).

B9.93 Key RF EW technologies in which the UK needs to maintain and develop capability include compact digital receivers and digital RF memories (DRFM) and compound semiconductor components for integrated RF devices.

Enhanced digital receiver technology, coupled with advanced de-interleaving signal processing to cleanly isolate and identify individual emitters, will result in greatly enhanced SA. Improved single and multiple platform geolocation, using Time and Frequency Difference of Arrival (TDoA, FDoA) techniques will allow RF EW systems to be used to cue targeting systems. **We will work towards airborne demonstrations of enhanced and networked Radar ESM.**

B9.94 Potential increases in localisation and ID accuracy could result in combat aircraft and tactical UAVs having ISTAR class ELINT capabilities, complementing those of strategic platforms. NEC information architectures may in turn have to reflect the growing ability of tactical assets to contribute to the creation of the electronic order of battle and the use of networked information in the tactical platform EW sensors.

B9.95 **EO/IR EW systems** The proliferation of short range EO/IR guided threats including man portable systems is driving our technology strategy to develop and rapidly exploit the UK's technical capability in this area. Rotary wing and fixed wing lift platforms are increasingly exposed to asymmetric threats, making the protection of these assets a priority. The main objectives in this area are for modular upgradeable compact self-protection systems; and an indigenous capability to develop and exploit countermeasure techniques.

B9.96 EO/IR EW systems include passive Missile Approach Warners (MAW) and Directed Infra Red Countermeasure (DIRCM) systems to interfere with missile seeker guidance.

B9.97 The UK has several US-sourced passive MAW systems in service, all of which operate in the ultra-violet spectral region. Research has indicated that transitioning to IR operation will result in superior performance. **The UK therefore aspires to ultimately deploy one indigenous type of IR MAW sensor across the air fleet and we are working in partnership with industry to that end.**

B9.98 The UK has developed a Compact DIRCM (C-DIRCM) laser head for airborne applications. We intend to utilise C-DIRCM as a common component of integrated air platform protection systems. **We will work towards compact modular self protection systems to allow rapid adoption or upgrade of self protection capability for air assets facing EO/IR guided asymmetric threats.**

B9.99 **We will work with the EW Tower of Excellence to better position UK industry to offer integrated compact and multifunction Air EW equipment solutions, working to align MOD investment and industry PV spending in common R&D plans and ensuring industry visibility of MOD analysis and requirements development.**

Through Life Capability Management of Fixed Wing Platforms

B9.100 This sub-section discusses the enabling attributes and characteristics that will allow progressive system change to be realised within a Through Life Capability Management (TLCM) context.

System and Avionics Architectures

B9.101 Adoption of the appropriate systems architecture is the key enabler to affordable through life employment of fixed wing platforms.

B9.102 The term architecture refers to a description of a system in terms of its physical components and their functional relationships. There are several scales of architectural descriptions – at the NEC level, the physical components are the platforms themselves, fixed infrastructure and communications networks. At the air platform level, the architecture comprises the internal avionics communication databuses, for example mil-std 1553B, and the major subsystems they connect – mission computers, displays, navigation systems, sensors and weapons (see figure 1)

B9.103 **Characteristics that support Progressive Change** The ability to adapt a system as service experience increases, operational needs **and** environments change or component obsolescence dictates, is dependent on the ease with which the system architecture can be reconfigured to accommodate new subsystems, including third party hardware and software. The key enabling characteristics are modularity and openness.

F15 CIT Avionics (BAES)

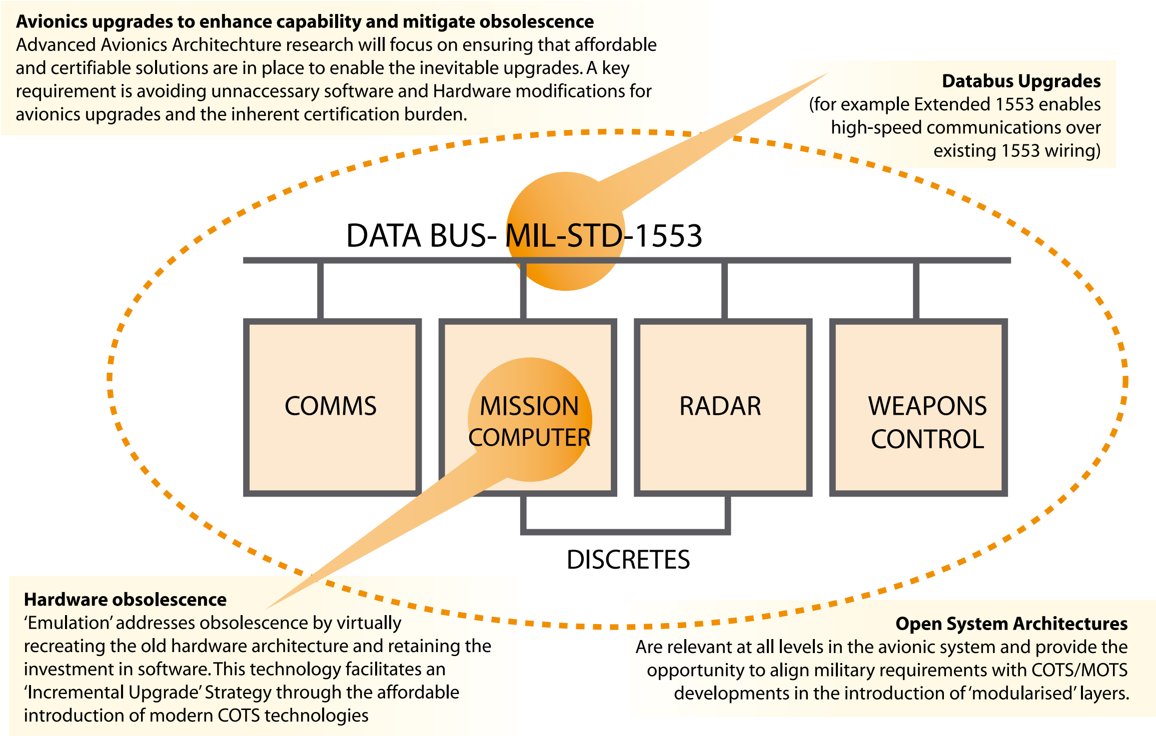


Figure 1. Aspects of Avionics Systems Architecture

B9.104 **Modularity** describes the extent to which the interfaces within a system are clearly defined and the system's physical, **functional** and contractual boundaries are well aligned. Without effective partitioning, a change to one component of the system can potentially propagate throughout the whole system, driving up the risk and cost of modest changes. Blocking the spread of change is the key to modular and incremental certification, wherein a safety case is built on the proof that subsystems are safe and their interaction across partitions is fully understood. Recertifying modified systems at a time and cost commensurate with the scale of the change, not the system, will be a key attribute of systems suitable for through life capability management.

B9.105 **Open systems** are systems for which the interface specifications are readily available. Importantly the open standards must also be widely subscribed to in the commercial marketplace – otherwise they are likely not to be viable in the longer term.

Technology

B9.106 Certification approaches to Modular Certification are currently being developed in industry and MOD funded research. We will build on this foundation by progressing from the commercially simple, single contractor mission system architectures currently under assessment to more complex multi vendor architectures with safety and security critical aspects, as well as increased commercial and contractual complexity. **We will progress Incremental Certification methods in order to derisk affordable progressive change and incremental acquisition.**

B9.107 **Databus** The 1553 databus standard is in widespread use in military avionics systems and as an open standard has been successful in promoting system level interoperability and supporting a competitive avionics market. It is now suffering in terms of data throughput and restrictive scheduling which can impact on ease of sub system change. Potential successors include extended 1553 higher throughput standard, as well as the adoption of commercial telecommunications protocols.

B9.108 **We will work with international partners and UK industry to identify the technological and economic implications of various databus standards.**

B9.109 **Avionics Obsolescence** Component obsolescence is a major issue, exacerbated by microprocessor lifecycles measured in months. Whereas adoption of new microprocessors would leverage the commercial world's developments, this is hindered by the time and cost of requalifying a new processor and software.

B9.110 **Emulation** Emulation technologies host original flight qualified software in virtual models of old processors, hosted on current COTS hardware. **We will identify opportunities to work with the supply base and international partners, including Australia, to assess and develop emulation solutions for UK military avionics hardware.**

B9.111 **Software** The need for affordable development and support of Safety Critical Software is discussed in more detail in the Cross-Cutting Technologies chapter. Of relevance to FW applications are formal model based methods for code generation.

B9.112 **UK Capability** The UK is intellectually strong across industry and academia in the related fields of avionics architectures, software intensive and safety critical systems and safety case development. **We recognise that this research area is underfunded in relation to its strategic importance.**

Avionics Architectures- the way ahead

B9.113 The effective TLCM of air platforms will be dependent on the realisation of affordable change to avionics systems. Drawing together the various strands of avionics including architectural models, software technologies, databus technologies and standards, obsolescence safety case and certification evidence, **we will work with the supply base to define the requirement for an exploitable architecture demonstrator which would be the basis of future platform TLCM-focused avionics.** This may also host UAV centric software based technologies such as autonomy and would be aligned with UAS requirements (see FW chapter UAV sub-section) but would also have significant read across to manned platform avionic upgrades including Typhoon.

B9.114 **We will work with the UK's expert supply base to develop and demonstrate flexible, modular and open platform architectures, utilised in the appropriate legislative, commercial and contractual context, to deliver Through Life Capability Management. The platform architecture is the key to realising the affordable through life employment of fixed wing and unmanned systems.**

B9.115 **Weapons Integration** Weapons integration costs and timescales are a major obstacle to the acquisition of new military capability. Noting the additional challenges imposed by the needs to progressively integrate new weapons on our current and future air fleets, we are reinvigorating our efforts to secure substantive reductions in weapon integration costs and timescales.

B9.116 Progress will be through streamlining and alignment of business processes, coupled with the adoption of technologies discussed elsewhere in this chapter. These include appropriate architectural/interface choices (see above) together with the employment of validated aerodynamic prediction tools (see aerodynamics) to cut down the extent and expense of live carriage and drop trials. **We will work with industry to develop and de-risk test and integration methodologies and regimes in order to deliver real benefit in this critical area** (see Complex Weapons chapter).

B10 Helicopters

Introduction

B10.1 The DIS makes it clear that MOD will look to the global marketplace to satisfy future helicopter requirements. However, AgustaWestland has the role of Design Authority (DA) for the majority of our existing helicopters and for Apache they have a co-ordination role for platform and systems. Lockheed Martin UK is currently the other major prime in UK for helicopters and is the DA for the Merlin Mk 1. Sustainment of DA capability within the UK is necessary to manage capability through life and requires a sufficiency in relevant skills to ensure a depth of knowledge, experience and effective succession management. Retention of systems engineering skills to address demands of future networked-enabled battlespace, and modelling and simulation will also be important.

Apache

B10.2 Support arrangements will be determined on value for money arguments, but they must be coherent with existing infrastructure and capabilities. MOD has started to implement revised and novel arrangements to support our current platforms through long term partnered Integrated Operational Support contracts and this will include working with Boeing on the Chinook fleet.

B10.3 Against this strategic backdrop a wide span of technologies and areas of expertise are needed to enhance and sustain current and future platform developments. The four key technology themes identified by the DIS are:

- **Platform Technologies**. UK instrumental in investigation of performance enhancements offered by improved blades that could lead to lower whole life costs and vibration through the BERP IV programme.
- **Mission systems**. UK plays a leading role in helicopter specific mission systems and Day-Night All Evironment (DNAE) technology that could offer exploitation opportunities to sustain this skill base.
- **Survivability**. Need to protect security of supply of a broad spectrum of technologies to underpin UK land and maritime capabilities and retain ability to manufacture, prototype, test and evaluate potential solutions using crew-in-loop simulation for tactics development.
- **Vibration Management**. UK knowledge of physics-level understanding of vibration transmission and an ability to design, prototype and validate active vibration management systems offers significant military and cost of ownership benefits.

Rear view of a Chinook

Priority Technology Areas

B10.4 The table overleaf gives a summary of key technologies for this sector, concentrating on the aspects applicable to the unique operating environment and configuration of a helicopter. Each of the technologies identified requires as a minimum an understanding of the operating environment experienced in UK operations where the flying techniques, tactics, etc may differ from our allies. Specific action points for each area are addressed in the sub-sections that follow the table.

Table 1. Summary of Priority Technologies

Area	Priority technologies	National Capability Requirement	Potentially through collaboration
Needs & Solutions	Operational and Capability Assessments	Validated operational and system performance models, simulations and test facilities to assess operational effectiveness, threat evaluation, risk and value for money of potential concepts or solutions to meet UK defence needs.	
	Concept design	Validated operational and system performance models, simulations, test facilities, rapid prototyping to assess design concepts for compliance with requirements including technical risk, duty of care issues, WLC, obsolescence and system-of-systems issues.	
	Requirements Definition	Requirements capture facilities for equipment and systems including operational performance, WLC, safety, measures of effectiveness & acceptance criteria.	
	System Design/System of System Design	Design, development, manufacture and testing of designs, and systems of systems knowledge and understanding to meet specified requirements.	
Physical Architecture	Configuration Design	Design, modelling, and rapid prototyping for the analysis of structural, aerodynamic, power plant, transmission train, sensor system and human factors constraints on configuration.	Power plant modelling and simulation
	Helicopter Airframe	Design, modelling and rapid prototyping of airframe structural and material properties, for example metal matrix composites, smart materials and multifunction materials. Interaction with other systems and the impact on through life issues.	Dynamics modelling and simulation
	Rotor control Actuation Systems	ICS to ensure that system level requirements can be met by potential solutions of hydraulic and electric actuation.	
	Rotor Systems and Transmission	Design and development capability to address performance enhancement and reduced cost of ownership through enhanced blade design (e.g. the inclusion of active elements to improve blade performance and reduce vibration)), active rotors, hubs, gearboxes and drive shafts.	
	Vibration Reduction	Maintain ability to design and validate active vibration management systems by a knowledge and understanding of the relevant materials, structures, systems and signal processing techniques. In particular, the use of single point and distributed actuators and the development of tools capable of coupled structural and aerodynamic analysis of airframe and rotor.	Maintain intelligent customer understanding
	Noise Management	Maintain ability to assess noise management systems to ensure adherence to EU noise legislation / duty of care. In particular in the areas of adaptive noise cancellation systems, 3D audio technology and acoustic signature measurement and modelling.	Maintain intelligent customer understanding
	Power and Energy Management	Maintain ICS to understand integration, operational issues and WLC implications of engines, APUs, environmental control systems, etc.	
	Flight Control Systems	System design, development, integration and test including safety critical software development and system acceptance of autopilots, stability augmentation and fly-by-wire.	Intelligent flight path systems
	Handling Qualities and Control	Ability to develop flight dynamic models and simulations to assess handling qualities and support development of flight control systems.	
	Advanced Configurations	ICS on advanced rotorcraft configurations, including tilt rotors and rotary wing UAV technology, through aerodynamics, structural, material and systems technologies to inform OA studies.	Tilt rotor, other advanced configurations, and exploitation of UAV technologies
Integrated Support	Health and Usage Monitoring	Understanding of degradation mechanisms of materials, structures and systems to maintain capability for requirement definition, effective and efficient health monitoring and ability to develop advanced diagnostic algorithms/software	
	Logistic Support	Understanding of logistic drivers and underlying science of life prediction defects and reliability and availability targets. To maintain effective support for legacy platforms through life and set availability targets.	Condition based maintenance
	Training Systems	Requirement capture and definition of acceptance criteria for individual and collective systems.	
	Airworthiness Assurance	Competent DA capability in the full range of science and engineering disciplines for legacy platforms and to maintain credible capability to act as self-regulating military airworthiness authority.	

Area	Priority technologies	National Capability Requirement	Potentially through collaboration
Survivability	Crashworthiness	Ability to assess risk/duty of care requirements, compliance of design solutions, support accident investigation with material, structural, aerodynamic and system knowledge.	
	Vulnerability	Specification, design, manufacture and integration of material, structural and system technologies and the ability to model and assess through life capability.	
	Signature Control	Specification, design, analysis, assessment and manufacture of material, structural and system characteristics that influence platform signature (radar, infra red, optical and acoustic). Validated operational and system performance models, simulations and test facilities to assess operational effectiveness, risk and value for money of potential concepts or solutions to meet UK defence needs.	Signature measurement and control mechanisms
	Electro-Magnetic Susceptibility	Specification, design, analysis, assessment and manufacture of material, structural and system characteristics that influence Electro-Magnetic Susceptibility	
	Defensive Aids	Detailed technical understanding of threat systems. Specification, design and manufacture of integrated systems, subsystems, technology and techniques for threat warning and countermeasures. Validated operational and system performance models, simulations and test facilities to assess operational effectiveness, risk and value for money of potential concepts or solutions to meet UK defence needs.	DAS integration and active countermeasures
	Aircrew Protection	Ability to assess personnel risk/duty of care requirements in man-made hostile environments, define requirements, design, develop, integrate and test solutions, through an understanding of material, structural and system technologies.	Studies of new techniques and concepts
Sensors & sensor Processing	EO Sensors	Maintain a capability in design, evaluation and integration of EO sensors (including Active and Passive mmW) to provide basic day and night navigation, pilotage, surveillance, mission performance, SA and targeting capabilities that have the potential of being extended to a poor visibility capability.	Sensors and data fusion from multiple sensors
	Radar	Maintain a capability in detailed understanding of radar integration, definition of system level performance requirements and the design, development and testing of solutions to meet capability requirements.	
	Electronic Surveillance	Maintain a capability in understanding of ESM integration, definition of system level performance requirements and design, development and testing of solutions to capability requirements.	
	Sonar	Maintain a capability in understanding active and passive sonar, sonar integration into the helicopter environment, definition of system level performance requirements and the design, development and testing of solutions to meet capability requirements.	
Payload Integration	Underslung Loads	Ability to design, develop and integrate systems, develop improved acceptance criteria and methodologies and assess effect on operational tempo.	Handling characteristics
	Internal Payloads	Maintain detailed understanding of load handling & systems integration issues to assess effect on operational tempo.	
	Role-fit Electronic Payloads	Maintain detailed understanding of systems effectiveness and integration issues, particularly with respect to power-by-the hour platforms.	
	Weapon Integration and Management	Maintain detailed understanding of systems integration issues to maximise effectiveness and minimise WLC.	

Area	Priority technologies	National Capability Requirement	Potentially through collaboration
Mission systems	Integrated Mission Systems	Maintain ability to design, evaluate and integrate mission systems within the mission computer as part of an NEC capability. An integrated mission system with open architecture will support adding new and extra capabilities with potential for growth and upgrades.	
	Tactical Decision Aids	Maintain ability to design, evaluate and integrate tactical decision aids that are critical to battlefield helicopters and provide an assimilation of battlefield data thus giving crew a real-time picture of the situation in the form of advisory information and recommendations.	
	Mission Planning Systems	Critical aspects of ground-based and on-board MDSS are commonality and interoperability fleet-wide. Commonality and interoperability has the potential to reduce the training overhead and WLC.	
	HMI	Optimisation of the design of the cockpit with respect to human factors. With critical technologies being visual and auditory display in an environment where there is extensive movement of the pilot's head, both hands need to be on the controls, substantial vibration is experienced within the cockpit and NVG compatibility is demanded.	Visual and auditory systems
	Secure Integrated Communications Systems	Maintain detailed understanding of technology to support systems integration.	
	CNS/ATM	Maintain ICS.	
	NEC Provision	Maintain detailed understanding of NEC to support helicopter specific issues including systems integration and system of systems aspects.	
	Autonomous/High Precision/Robust Nav Systems	Maintain ICS	
	Local Traffic Management and Collision Avoidance	Maintain ICS	
Systems Integration & Environment	Open Architecture Systems	Maintain detailed understanding of architecture development to support requirements definition, systems integration, WLC and obsolescence planning.	
	High-Speed Data Networks	Maintain ICS.	
	Day/Night/All Environment Systems	Maintain key prototyping and mission simulation facilities in addition to the sensor and HMI technologies identified above.	
	Maritime	Define overall system level requirements; design, develop, integrate and test optimal solutions for air and sea platforms.	
	Protection Against Adverse Environments	Requirements definition, predictive capability, and ability to optimise system design through a knowledge of material, structural, and system.	Ice accretion modelling. Studies of new techniques
	EMC	Maintain ICS sufficient to ensure helicopter operational capability is maintain through life.	

B10.5 With a limited research budget and a directed OTS (Off-The-Shelf) procurement strategy, inevitably there are areas where MOD investment is considered less of a priority. For example, design and development of rotor systems, and an understanding of the materials, structural dynamics, and operating environment are crucial to a successful helicopter design: but these are skills and technologies available globally, and consequently do not rank highly for MOD investment. Whereas, for example, many of the skills and technologies associated with the development of effective signature control (such as modelling capabilities and an understanding of the physics of signatures) are critical, often specific to UK operational capabilities, and where security of supply is paramount and, therefore, rank highly for MOD investment.

B10.6 Other considerations for technology investment are whether being tied to a foreign source of supply ties the UK into a cycle of obsolescence replacement that is unaffordable, or where the foreign source only gives access to some attributes of the technology whilst others, such as software source code, are unavailable. However, MOD investment can be used to create and maintain centres of excellence in technology, particularly where UK is known to have a technological advantage that can further our wider interests.

Needs and Solutions

B10.7 This technology group is recognised as high priority by MOD and Industry, and is characterised by the demand for substantial modelling and assessment capabilities across all technology fronts, (aerodynamics, materials, structures, control technologies, threat assessments, flight dynamics, signature control, etc) but typically at a relative high level of assessment rather than detailed calculations. Formulation of these models requires substantial knowledge and experience within the UK skill base, but the nature and size of the UK market and the trend in military projects, where life cycles are typically 25+ years, has reduced the number of concurrent projects to develop these skills.

B10.8 The DIS judged that the professionalism and effectiveness of the skill base is best sustained by setting 'high tech' engineering challenges. Such challenges are typically only found in helicopter design development and demonstration activities and these provide the skills across all the technology fronts identified above. The increasing trend towards a small number of long-life projects may mean some key skills are utilised only once in a working life, whereas wide-ranging skills and experience are considered vital to maintaining the ability to provide intelligent solutions to capability gaps.

B10.9 **In the short-to-medium term, the Merlin Mk1 Capability Sustainment Programme (CSP), the investment in Future Lynx, and MOD funded studies are judged to include the necessary challenges to maintain the design authority skills, modelling and assessment capabilities, to provide intelligent solutions to capability gaps. In the longer term it may be necessary to set out new strategic technical challenges, linked to future concepts.**

Survivability

B10.10 This is another group of technologies seen as of substantial importance by MOD and Industry with a strong supplier base within the UK and opportunities for the exploitation of UK technology and skills, some of which is world-class. Areas of strength in the UK include threat analysis, DAS integration, expendable countermeasure technology, paints and coatings, acoustic signature control, and a systems approach to survivability. The technologies underpinning this capability are numerous and include signal processing, data fusion, radar, EO sensors, EO protection measures, signature control, electronic warfare technologies, materials, and modelling capabilities.

B10.11 On-shore ownership of the above underpinning technologies would provide UK with an ability to support capability through life, and ensure operational sovereignty. However, ownership of all these technologies is unaffordable and the importance of specific technology changes with time, for example, because of a changed threat environment or technological developments, as discussed in the earlier chapter on Cross-Cutting technologies. The vital UK Capability here is to be able to model and analyse the technical and cost benefits of different solutions. A similar strategy applies across the other underpinning technologies.

B10.12 **The MOD will invest in this group of technologies in a balanced way to retain a flexible and agile response to changes in the threat environment and technological changes. Investment in UK has also provided world-class technology that maintains UK access to US technology programmes. MOD recognises that substantial additional benefit is gained from this relationship and will invest in the areas of UK strength identified above to foster this relationship.**

Interior of Merlin helicopter of 824 Naval Air Squadron

Human-Machine Interface (HMI)

B10.13 The Human Machine Interface is a high priority technology with substantial commonality to other sectors, but with key features unique to helicopters. It is one of the enablers for DNAE operations and accordingly is of high priority to MOD. The technology is shared across many other sectors and is therefore covered more comprehensively in the cross-cutting technologies chapter, but has key features unique to the helicopter operating environment. HMI is an

integrating element of the Mission System Solution that enhances user effectiveness. Multiple sources of information are rationalised into understandable and actionable information that allows the user to perform more effectively. Crucial technologies are visual (symbology, data fusion, etc) and auditory displays, in a demanding environment where there is extensive movement of the pilot's head, the need for both hands to be on the controls, and where substantial vibration is experienced within the cockpit. NVG compatibility is also demanded.

B10.14 **HMI is substantially driven by MOD safety, security and operational considerations and as a consequence MOD will invest in visual and auditory display technologies.**

Crew protection

B10.15 Crew protection solutions are specific to helicopters but involve the exploitation of material, structural and system technologies ranging from armour to clothing. Consequently, **MOD will drive the development of crew protection through the research programme, ensuring that its priorities on duty of care are addressed as well as satisfactory compliance with legislation.**

Environment

B10.16 This area is a high priority for the MOD and the technologies that underpin the ability to have DNAE operations are seen as vital to UK operations. DNAE utilises a range of technologies such as sensors technologies (IR, Passive and Active mmW), display technologies, flight control and dynamics, data and image fusion. DNAE systems are a key UK industrial strength, but there is often reliance on offshore sourced components and subsystems. Shortfalls in UK capability in these technologies are gradually being addressed by MOD and industry investment but DNAE solutions often involve exploitation of existing technology in an innovative manner, mmW technology being an example.

B10.17 Exploitation of the DNAE technology can often be difficult because embedding new technology in OTS platforms is costly. This is even more of an issue when considering technology insertion in platforms purchased offshore. This can be overcome by ensuring that technology is sufficiently mature to be able to demonstrate benefits to platform suppliers and enable system integration. Consequently, demonstration of DNAE technologies at a high level of maturity is vital to enable UK industry to bid into off-shore programmes.

B10.18 **MOD will work with Industry to fund high-level demonstrators in DNAE technologies for timely insertion of the technology in future acquisition programmes.**

Physical Architecture

B10.19 In this technology group there are substantial strengths within the UK, but these could be adversely affected by the directed OTS procurement strategy for helicopters. OTS procurement can limit the scope for technology insertion and offshore OTS can limit access to IP. The scarcity and longevity of projects exacerbates the ability to maintain a credible onshore skill base. Particular UK strengths include rotor blade technologies (composites, aerodynamics, structural dynamics), airframe design (materials, structures, optimisation techniques, dynamics, vibration), vibration management, environmental control systems, and fuel systems. MOD views Noise Management as a priority to meet its commitments to duty of care to personnel and to demands of legislation.

B10.20 **MOD will drive the development of Noise Management technology for helicopters.**

B10.21 The absence of any short/medium term MOD interest in advanced configurations, such as tilt rotors, may create a skills gap that cannot be filled from within the UK to serve any long-term need for an intelligent customer assessment of emerging novel configurations.

Way forward for Helicopter technologies

B10.22 The partnering relationship with AgustaWestland to realise business transformation within the company must enable them to sustain the required skills base in the long term, with less reliance on MOD investment. The AgustaWestland corporate strategy must look to the global market to sustain its skills by PV funding, Italian MOD investment, military export sales, civil helicopter programmes and partnerships with other helicopter manufacturers. Some minor realignment of MOD and PV investment in the key technologies will be required to address any shortfalls in the short term, but this requires a more detailed analysis of MOD, AgustaWestland, and other key players' investment plans and technology priorities. Consequently, as part of this overall business transformation, **MOD will establish a Rotorcraft Technology Steering Committee, by the end of 2006, to co-ordinate and jointly plan investment by MOD, DTI, AgustaWestland and the other major players in the sector.**

B10.23 Merlin CSP and Future Lynx will maintain and extend existing skills, but will not create the challenges presented by consideration of advanced configurations that will maintain a long term UK capability in the technologies discussed earlier. Whilst US military and the civil market are considering the utility of advanced configurations, such as tilt-rotor technology, current MOD planning suggests that a demand for a step change to advanced configurations is unlikely before 2040. MOD investment in these configurations is therefore unlikely to be considered before 2020. However, AgustaWestland benefits from a joint venture with Bell Helicopter in the development of the BA609 civilian tilt-rotor and is the other main partner with Eurocopter in the European Commission funded ERICA programme.

B10.24 **MOD will cover its interest in future configurations through an active technology watch of the ERICA programme. MOD will work with the DTI to influence the direction of the ERICA programme and enable exploitation and technology transfer to defence projects if appropriate.**

Maritime

Introduction

B11.1 This chapter addresses those areas covered by the maritime chapter of DIS. For general weapons, DEW, above water sensors, maritime air systems and maritime C4ISTAR technologies also see the relevant DTS chapters.

B11.2 The Maritime Sector is that element of the industrial base which designs, builds, supports and disposes of all naval platforms and systems. It encompasses ships, submarines, and their integral systems; including propulsion, services, combat systems and combat system elements and their effective integration.

B11.3 The 2003 Defence White Paper, 'Delivering Security in a Changing World – Future Capabilities', emphasised the importance of versatile maritime expeditionary forces to project power across the globe in support of British interests and delivering effect on to land at a time and place of our choosing. The sea offers an opportunity for UK Forces to operate with a degree of security and persistence, without reliance on the territory of others for basing. To take advantage of this, the Royal Navy will in future need to be an agile, network enabled expeditionary force able to switch between missions and tasks and to interoperate with chosen allies. The force will have the ability to deliver and sustain a full range of missions: from small highly focussed interventions with Special Forces, to large, high intensity coalition operations.

Concept drawing of Type 45 Destroyer

B11.4 The cost and sophistication of maritime systems are increasing, and the need to pull through technological solutions into the front line to retain an operational edge is ever more demanding. Technology, along with other lines of development, underpins the delivery of military capability across the maritime sector. The UK leads the world in a number of technologies in this sector, but needs to ensure that the limited investment available to develop and sustain technologies is optimised.

B11.5 DIS calls upon MOD and industry to work together to ensure the effective structuring and execution of warship and submarine building in the UK. MOD has formed a Maritime Industrial Strategy (MIS) team to take the issues forward with industry. The maritime chapter of the Defence Technology Strategy has been formulated to complement MIS as well as support the capability requirements of the future versatile maritime force.

Priority Technology Areas

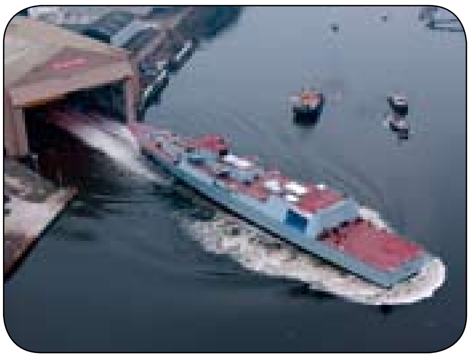
B11.6 Technology investment decisions will be made against the following UK capability framework:

- Design complex ships and submarines, from concept to point of build; and the complementary skills to manage the build, integration, assurance, test, acceptance, support and upgrade of maritime platforms through-life.

- Retain a minimum ability to build and integrate complex ships in the UK.

- Retain all of those capabilities unique to submarines and their Nuclear Steam Raising Plant (NSRP), to enable their design, development, build, support, operation and decommissioning. Due to national security, NSRP issues are addressed in a classified annexe to the DTS.

- Retain the ability to develop complex maritime combat systems and their integration into warships and submarines.



Launch of HMS Daring, first of class Type 45 Destroyer

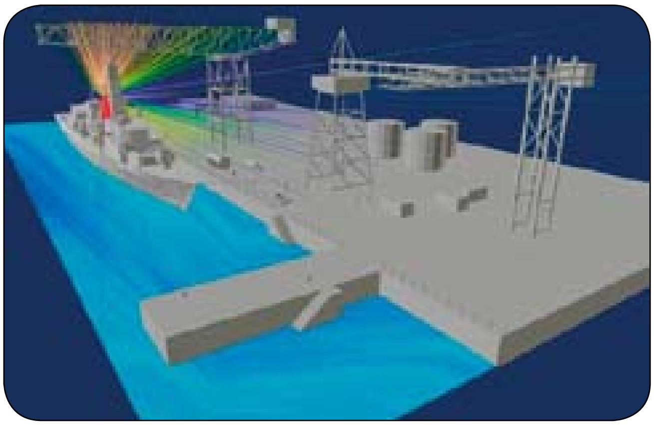
B11.7 Additionally technology is required to play a major role in meeting current maritime capability issues such as (not in priority order):

- Situational awareness, particularly for littoral operations where the increased clutter and more complex environment stresses sensors and decision-making techniques.
- Force protection such as identifying and countering irregular and asymmetric threats which requires the development of accurate, all weather, day/night sensors able to extract target information to feed algorithms that predict intent, and systems such as unmanned surface or air vehicles able to respond to the threat remote to the ship
- The ability to rapidly redesign, re-use, adjust maritime capability in order to respond quickly to changing operational scenarios through implementation of technology such as open architectures, modular systems and integrated sensors.
- Reducing the cost of procurement, ownership, and through life-capability management of all maritime systems.
- Interoperability within the UK and with US, NATO and ad hoc alliances. e.g. internet-protocols, control of remote vehicles, sharing of tactical picture information.
- Monitor and exploit disruptive technologies, such as directed energy weapons.
- High tempo mine-countermeasures particularly in shallow water; e.g. hyper-spectral imaging, autonomous remote vehicles.
- Future anti-submarine warfare (ASW) in littoral areas (remotely deployed sensors, UAV and space based sensors and wide-band active sonar).

B11.8 A wide range of studies are also shaping the Maritime Sector. These include:

- The Maritime Industrial Strategy.
- The Marine Systems Development Strategy.
- The Future Mine Countermeasures Strategy.
- The Survivability Strategy.
- All Arms ASW.
- Future Submarine Programme (FSP).
- Sustainable Surface Combatant Capability (S2C2).

B11.9 The outcome of these and the results of capability audit and technology investigation, will have a significant influence on the formulation of the mid to longer-term maritime defence technology strategy that supports the delivery of the UK's future maritime military capability



Modelling the effect of in-harbour blast on a Type 23 frigate

B11.10 The maritime research programme is now firmly aligned to requirements set against capability issues and the need for robust advice. It is also being formulated to be adaptive to changing needs. The summary table overleaf gives details of the priority technologies and the areas where there is a need to retain national control.

Table 1. Summary of Priority Technologies

Area	Technology Priorities	National Capability Requirement	Potentially through collaboration
Concept generation, design and integration of complex maritime combat and platform systems	Systems Engineering/Integration including EMC, system architecture, modularity, human factors, cost engineering, knowledge management and technology insertion. (See also cross cutting chapter).	Design and development and systems integration skills to enable cost effective specification, assembly, testing, acceptance and TLCM of maritime systems and the manufacturing, assembly and testing of submarines and their disposal.	Collaboration to maintain ICS possible.
	Modelling, simulation and assessment	Access to and skills to understand and use validated models of systems to generate concepts, assess options and designs, and undertake trade-off studies and to enable validation, verification and certification of deployed capability.	
	Open Architecture and systems; includes: reusable adaptive software, open hardware, inherent quality of service metering and modular systems.	Deep understanding of methodology, business models, benefit and application of open systems. Skills to understand and accredit third-party systems.	With US to maintain ICS and to foster wider adoption of open standards.
	Safety and Assurance. Includes, weapon system clearance, safety critical software, stability, structures1, NBCD, escape and rescue, safety case development and management, risk management and selection and application of standards.	Assessment, certification of systems and systems-of-systems (incl ships and submarines) via development, understanding and application of suitable standards and analysis and testing to enable design, equipment, whole system and material state approval through life. Includes assessment of defects such as corrosion, damage, cracks, out of tolerance shapes or material properties on submarine hull strength and the underpinning physics.	Where possible to benchmark and peer review UK approach and maintain ICS.
	Environment including impact of maritime operations on the environment and how to mitigate them, how to meet future legislation without undue constraint on maritime operations and how to exploit the environment to military advantage especially sensor effectiveness.	Deep understanding	Where appropriate to maintain ICS and development of international standards for environmental protection.
Integrated Survivability	Threat assessment across whole spectrum of above and underwater threats including IEDs.	Deep understanding of current and emerging threats and their effect on maritime operations and definition of countermeasures.	
	Survivability Models, includes Susceptibility, vulnerability, recoverability, effectors allocation and defence coordination and integrated platform and force level survivability models.	Access to suitable tools, design and development and systems integration skills to enable ICS to support cost effective specification, design, acceptance and through life management of the survivability of the maritime force.	Collaboration with US and through TTCP to maintain national expertise. Test facilities may be obtained overseas.
	Signature control for submarines. Incl: - Acoustic materials and structures - Non acoustic signatures	Design, development, systems integration, testing, manufacture and TLCM to meet signature requirements; including underpinning technology such as materials, structural design and physics.	Collaboration with US to maintain national expertise.
	Adaptation of COTS/MOTS.	Design, development and systems integration including access to design codes and standards to enable survivability aspects of adopting COTS or MOTs solutions to be considered.	

Area	Technology Priorities	National Capability Requirement	Potentially through collaboration
Combat Systems	Models, simulation and assessment	Intelligent customer, design and systems integration to determine balanced combat systems across threat spectrum and technology insertion for TLCM. Deep understanding of the options for progressive/graduated response. Requirements definition	
	Torpedo Defence incl: – Operation in the littoral and shallow water; – Counter-countermeasures – Countermeasure launchers – Active TDCL – Cooperative systems – Counters to wake-homing weapons	Threat analysis, design and development, systems integration and test and evaluation.	Limited collaboration possible but UK to retain ability to insert improved countermeasure techniques into expendable systems.
	Sonar includes: – Vibration engineering and platform design to minimise self-noise. – Signal and data processing. – Automatic Detection Classification and Localisation, e.g. for MCM. – Sonar performance modelling – Transducer technology e.g. thin arrays and optical systems including underpinning physics. – Compact, wideband, low power sensors for weapons and underwater vehicles. – Counter-countermeasures – Weapon and other off board system cuing and control. – Power, bandwidth and processing technology for remote systems and sensors. – Data recording and retrieval.	Design and development, systems integration, test and evaluation, and through life management of submarine (plus manufacture and assembly), surface ship low frequency active wideband, mine-countermeasures, weapon and off board system sonar. Components may be sourced offshore. MOD research funding will not address inboard hardware as it is assumed this will be delivered through open systems architectures and COTS processors. Underwater Sensors Tower of Excellence to be used to monitor and advise on sonar programme.	Collaboration to be used to maintain ICS, benchmarking and peer reviewing sonar activity, and develop future programmes where appropriate.
	Above water sensors particularly to overcome high levels of clutter and stressing targets (see also cross cutting chapter): – Radar, EO, IR, BIL, ES – Sensor and environment modelling – Non-cooperative target recognition – High resolution sensing and imaging over land and sea – Multi-sensor integration – Adaptive systems – Exploitation of COTS technology	Design, development, systems integration, testing and evaluation of sensors and integrated sensor suites.	Collaboration to be exploited where appropriate.
	Information management (see also C4ISTAR) includes; – Modelling and assessment – Secure, LPI systems – Underwater acoustic communications. – Acoustic to RF. – Security of multi-level, meta-data based and IPv6 systems – Architectures – Intermittent connectivity – Susceptibility of detection – Compact RF antenna design – Self-forming and adaptive ad-hoc networks – International interoperability – Distributed networks and sensors and collaborative planning – Assured quality of service – Tactical picture compilation and decision aids e.g. Automatic Situational Assessment – Strategic communications. Signal Processing. (see also C4ISTAR) including: – Open, digital systems – Environmental adaptation – Automatic Target Recognition – Assessment of 3rd party algorithms – Effective operation in the littoral – Sonar algorithms – Multi sensor integration and data fusion – Torpedo homing. – Image processing. – Sensor control.	Design and development and systems integration skills to enable cost effective specification, assembly, testing, acceptance and TLCM of maritime combat systems Deep understanding of the SA provided by above and underwater systems both onboard and off-board and the interface with operators and other systems Deep understanding of the security of information management systems and assurance and accreditation of such systems. Design, development, systems integration, testing and evaluation of signal processing techniques across the spectrum of combat system elements. Identify and exploit innovative approaches.	Collaboration to be explored to facilitate interoperability. Collaboration possible but must sustain UK capability to design, evaluate, test and integrate algorithms into sensors, weapons and CBM systems.

Area	Technology Priorities	National Capability Requirement	Potentially through collaboration
Uninhabited Systems	Models and assessment tools	Access to models and tools to enable intelligent customer, balance of investment and benefit assessment of systems.	Collaboration (e.g. NATO undersea Research Centre for UUV) to be exploited to support UK ICS and for test and evaluation..
	Integration into maritime platforms and wider force structure includes: – Effective handling systems for launch and recovery, and – Integration of capability.	Systems integration to ensure the effective use of uninhabited systems from maritime platforms.	
	Integration of payloads.	Design and systems integration of interfaces for payloads and specific military payloads where they are not available OTS.	
	Guidance, navigation and control	Design and systems integration. Deep understanding of autonomous operation.	
Platform	Power generation and management incl. – Architecture models – Use and adaptation of COTS – Power switching – Fault management – Electrification of auxiliary systems. – Compact power for off-board systems.	Technical competence to ensure the UK is an intelligent customer of future power systems for complex maritime platforms including design and systems integration skills and TLCM. Detail to be developed in conjunction with MOD Marine Systems Development Strategy.	To maintain ICS and systems engineering skills. To support development of specific military only technology.
	Hydrodynamics includes: – Design of quiet propellers and pumpjets. – Model and predict manoeuvring performance of submarines. – Model manoeuvring of submarines with other vehicles such as discharged weapons or other underwater vehicles or deployed stores. – Validation of models – Adaptation of COTS CFD tools	Design and development, and in-service support for quiet submarine propulsors and the safe operation of underwater systems. Skills to specify and assess performance of OTS and 3rd party solutions.	Test facilities may be utilised through collaboration provided UK acoustic signatures are not compromised.
	Submarine atmosphere control includes: – Air purification and monitoring. – Broad atmosphere sampling – Centralised and integrated system architectures – Modelling and assessment of new technologies and techniques	Design and development, systems integration, performance assessment. Science to assess health impact of contaminants In the absence of applicable civil standards and legislation, maintain a safety management system for atmosphere safety, and show that it is as safe as civil processes Minimal investment until plans for long-term submarine programme defined	Assessment of options for SAC systems

Concept generation, design and integration of complex maritime systems

B11.11 Systems Engineering/Integration skills are key to bringing together all the components of the combat system and platform to ensure that they work effectively. Much of the technology and skills to design and integrate complex warships and submarines exists now in the UK, but skills such as naval architecture, marine engineering and combat system engineering, need to be maintained and developed to support the next generation of complex maritime combat systems and platforms and provide through life support to extant platforms. To remain current and be effective these skills need to be exercised regularly.

Artists impression of Astute class submarine © BAE Systems

B11.12 Open systems, modularity, environmental compliance, rapid certification of systems, EMC/EMI, maritime military standards, safety assessment (e.g. certification of submarine structures from build to disposal), modelling, simulation and assessment tools for systems analysis are a few of the enabling technologies requiring maintenance and development. Indeed some of these skills and technologies, such as structural design, are essential requirements of a competent owner and operator of warships and submarines. The output of MIS, S2C2 and FSP will assist MOD and industry to understand the balance of investment in such enabling technologies and help focus MOD and industrial investment priorities.

B11.13 Cost will also be a key factor in delivering future maritime capability so technology such as multi-use sensors and modular systems needs to be exploited wherever possible. Rapid concept design capability will be required to aid development of platform and combat system options along with accurate cost estimates from the earliest stages. Open architecture is seen as a key enabler to delivery of future systems but we need to expand the focus of recent work from software to explore platform-wide open hardware architectures to facilitate rapid and cost effective insertion of technology (e.g. to be able to readily replace a diesel generator with a fuel cell or integrate future combat systems such as off-board systems or directed energy weapons).

B11.14 **MOD will invest in research into future cost-effective combat system and platform architectures and technologies. MOD will explore the benefits of open systems and work with industry to understand the business and technology models to facilitate its exploitation.**

B11.15 **MOD will, through MIS, S2C2 and FSP, identify longer-term investment priorities in enabling and underpinning science and technology supporting design, build and through-life management.**

Integrated Survivability

B11.16 Threat assessment across the spectrum of maritime threats is vital to the understanding and appropriate development of military capability, especially as littoral operations present new threats to the maritime force. Underpinning this is the ability to analyse weapon effects and understand the appropriate courses of action and their relative costs and to inform selection and deployment of countermeasures. This is a national requirement.

B11.17 The aim of affordable integrated survivability is to be able to understand the balance of investment between vulnerability reduction, susceptibility improvement and recoverability of platforms and the maritime force. Successful management of this trade space is one of the keys to delivering cost-effective current and future platforms and managing survivability through life. This requires the adaptation and development of cost-effective models that predict the consequences of military operations. MOD is developing such an integrated survivability model, known as Mission, for the above water domain. There will be no new significant research programmes for above water signatures until this work reports. Signatures capabilities will be sustained at a minimum level in the near-term by placing research aimed at understanding survivable surface systems for littoral operations and providing advice to operations. Likewise, there will be minimal research into shock mitigation technology but there will, however, be studies into cost-effective battle-damage repair systems, such as blast resistant coatings, to reduce the vulnerability of extant platforms. MOD will also study mitigation of the effects of IEDs.

Testing coatings on steel panels

B11.18 The ability to design, sustain, upgrade, modify and integrate low signature – both acoustic and non-acoustic - submarines is a key national capability. Future research will investigate signature implications of operating in the littoral and integrating COTS components and systems, and examine affordable signature reduction techniques – e.g. potential of super-conducting coils to reduce the cost of degaussing systems. Much of this work will be undertaken in collaboration with the US.

B11.19 The UK supplier base needs the necessary skills to understand the survivability trade space for designs and to be able to fully understand the survivability implications of exploiting COTS technology.

B11.20 **MOD is developing strategies and tools to inform investment priorities for ship survivability. Pending the outcome of this work, above water signature development will be constrained and vulnerability research will focus on support to operations. MOD will carry out research of underwater signatures and their reduction technologies with a focus on littoral operations. MOD will utilise collaboration in development of survivability technology.**

Combat Systems

B11.21 **Models, simulation and assessment.** Modelling and simulation of systems to support sensible capability and technology selection decision-making is a fundamental part of the maritime programme.. It will be essential to produce cost effective models that are multi-use, as accurate as they need to be and have clearly defined performance parameters. Industry also develops models for product development so MOD and industry will need to work together to mutual benefit to avoid duplication. MOD is currently studying, through initiatives such as the Underwater Analysis Framework, the approach to model formulation, development, integration and use to inform capability management and investment decisions across the lines of development. Where models are part of an acceptance process, the UK must retain ownership, a full understanding of them and the ability to modify such models.

B11.22 **Through 2007, MOD will work with industry to identify an appropriate framework for the development, use and access to appropriate maritime numerical models.**

B11.23 **Torpedo Defence**. Torpedo defence embraces the detection, classification, localisation (DCL) and countermeasures to underwater weapons. The UK must retain the ability to exploit and develop signal processing techniques and associated algorithms that enable active and passive sensors to cue a ship or submarine to take defensive action including the opportunity to deploy effective countermeasures. This requires a detailed technical understanding of the threat and its employment. It does not mean that the MOD will constrain procurement of the technology to the UK. Single crystal transducers offer the ability to develop wide-band, reactive countermeasures in a useable package. Networking of countermeasures, signal processing within countermeasures and concepts to counter wake-homing torpedoes will be addressed. Networking of countermeasures offers the potential to increase self-defence capabilities and also provide cost-effective force defence. Work will align to the 5 and 10-year technology insertion opportunities of existing stores.

B11.24 Consideration will be given to technology to deliver anti-torpedo capability once the outcome of the research to de-risk active sensors for torpedo detection is known.

B11.25 **MOD will research relevant torpedo defence technology including DCL, elastomeric launchers, reactive countermeasures, networked countermeasures for force defence and signal processing.**

B11.26 **Sonar.** UK sonar technology is considered to be world-class and needs to be maintained to ensure the UK is able to counter the growing threat from capable SSKs and to operate submarines safely and effectively. Sensor design knowledge covering a wide frequency range, including extended bandwidth, needs to be retained onshore. Inboard hardware will be provided by COTS processors and enabled through open systems architectures.

B11.27 MOD's sonar research aims to de-risk and demonstrate affordable technology to pull through to current and future sonar systems. The Underwater Sensors Tower of Excellence (UWS Tower) will monitor and advise on strategy and development in this area. Projects intend to:

The 'Generic Acoustic Processing System' used for analysis of sonar data

- Characterise the underwater environment, particularly the littoral to aid sonar data processing for DCL, underwater picture compilation, adaptive sonar performance, and underwater communications.

- Improve signal and data processing through better use of data, rapid insertion of algorithms, passive synthetic aperture processing, low frequency active and wide bandwidth systems leading to improved DCL, and enabling ATR and the minimisation of false contacts.

- Provide new options for transducer architectures e.g.: compact projector designs such as Free Flooding Rings, thin flank technology and fibre hydrophones and also consider longer-term exploitation of alternative technology such as optical sensors, single crystals and development of underlying physics.

- Develop performance models for sonar.

- Limited exploration of multi-static sonar systems targeted at wider exploitation of S2087 capability.

- Address the human machine interface.

- Understand and cater for environmental effects of sonar.

- Maintain UK expertise in compact, digital torpedo homing and associated signal processing.

B11.28 Collaboration with US and France will be used to benchmark sonar and further specific technology aligned to procurement activity. MOD has contracted with a consortium (known as Osprey) of academic, SME and larger industrial entities to deliver underwater sensor research.

B11.29 **MOD will research sonar and associated signal processing to support submarines, surface ship low frequency active wideband systems, mine countermeasures and underwater weapons and remote systems. The UWS Tower of Excellence will be engaged to support this work. MOD will not invest in research of inboard hardware technology. MOD will seek collaborative opportunities wherever appropriate.**

B11.30 **Above water sensors.** Above water sensor technology challenges include:

- High-efficiency radar transmitter devices packaged in small reliable line-replacement items;
- Highly stability for advanced feature extraction and dealing with clutter;
- EO devices that overcome propagation for all weather, day/night surveillance;
- RF devices that overcome mutual interference and are resilient to jamming;
- Digitisation to provide flexible and adaptable integrated sensor systems;
- Exploitation of COTS technology to control costs;
- Balance sensor suite able to readily change role;
- Adaptive systems;
- Real-time assessment and assurance of performance;
- Space and UAV sensors for maritime surveillance including ASW and MCM.

B11.31 Recent research has indicated that fusing data from different integrated sensor systems greatly improves overall sensor suite effectiveness. There is already a strong research programme de-risking sensor technology to provide advice and options for a balanced sensor suite for future platforms.

B11.32 **MOD will evaluate and demonstrate sensor and integrated sensor performance in the maritime environment and the feasibility of establishing an above water Integrated Sensor Evaluation Environment (ISEE). Collaboration with allies will be used to deliver maritime specific research where appropriate**

Maritime situational awareness

B11.33 **Information management.** .A complex maritime combatant contains a multitude of information systems in a relatively small space. Real-time, networked connections between force elements, off-board systems and wider sources will significantly enhance the situational awareness of the maritime force as a whole. .

B11.34 Accreditation and assurance of the security of multi-level, interconnected and network enabled systems present significant challenges to the maritime domain particularly as COTS technology such as internet protocols are exploited. This complex problem will grow as remote systems join the force and interoperability - with the US for instance - places greater demands on information management. It is essential that the UK is able to fully understand information system architecture, how to construct it to meet maritime capability needs, and how to provide system integrity and resilience. Whilst components may be sourced offshore, the UK must be able to design the architecture and undertake systems integration, testing and accreditation and through life management of the systems.

B11.35 Submarines and other underwater elements will only realise their potential contribution to the Versatile Maritime Force if they are able to respond to local command and control, and to deliver their effects at the same tempo as the other elements of the force. Integrating the underwater domain in this fashion presents a number of technological challenges. The most pressing need is for command, control and communication (C3) facilities for submarines at speed and depth.

B11.36 Acoustic communication is a specialised technology, which will form an important component of future underwater networks and of the submarine C3 capability. The technologies that we seek to develop and maintain include:

- High performance, compact RF antennas.
- Self-forming and adapting ad-hoc networks.
- Methods for controlling and prioritising traffic in a high emission controlled environment.
- Assured quality of service.
- Adaptive environmental underwater communications and associated underpinning science.
- Covert communications techniques such as low probability of intercept waveforms.
- Exploitation of standards which will facilitate interoperability, for example the use of Internet Protocol messaging, MODAF and service oriented architectures.

B11.37 **MOD is now considering the concepts of deployment and operation via an "All Arms ASW" study. Due to report during 2007, this will inform the next phase of the technology development.**

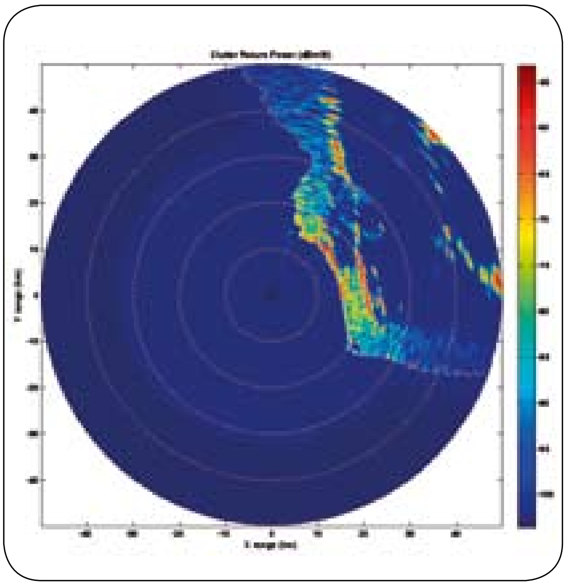
B11.38 Of growing importance for the maritime domain is the need to manage the information load on operators. Data fusion, tactical picture compilation, automatic situational assessment, automatic target recognition and decision aids integrated with other support functionality such as environmental models and real-time performance assessment are techniques that require development to assure effective future information management systems. There is currently a good understanding of such techniques in the UK, which needs to be maintained and developed to deliver future capability. A combat-system engineering model is being developed to help identify and understand the system integration issues for future combat systems. The research programme will continue to study these issues to generate and maintain a deep understanding and options for delivery of this capability. Such techniques will be exploited through the next generation of command systems and the implementation of open systems.

B11.39 **MOD will invest in research of maritime information architectures and develop options for future systems. Collaboration will be used to facilitate interoperability.**

B11.40 **MOD will sponsor development of underwater network and communications technology but research will be at a minimal level to support studies into concepts of operation and deployment.**

B11.41 Signal Processing. Signal processing is a fundamental technology that underpins maritime combat system effectiveness through life. It is a UK strength for electronic surveillance, sonar and maritime radar systems. It provides the military edge for many systems and enables effective exploitation of COTS and MOTS systems. Signal processing must be sustained and developed in the UK to maintain this edge, particularly for UK sensitive systems such as electronic surveillance. This will be achieved through placing of research that aims to:

- Develop Automatic Target Recognition (ATR) for above and underwater sensors.
- Enable detection and tracking of stressing targets in high clutter and difficult environments.
- Examine options and develop kill assessment techniques.
- Develop multi-sensor integration.
- Develop torpedo homing and defeat of countermeasures.
- Improve detection, classification and localisation of mines.



Radar data

B11.42 **MOD will seek signal-processing techniques worldwide and will invest in research to sustain the UK signal processing capability and the ability to control our sensitive systems and modify and update them readily.**

B11

Maritime

Uninhabited Maritime Systems

B11.43 Unmanned systems, whether UAVs or UUVs (referred to here as UXVs), offer the potential to deliver a range of existing and new military capabilities. Modelling, experimentation, technology and system development with UXVs will enable their contribution to the maritime force to be determined to inform decisions; understand the strategy for successful integration into the combat system and focus future platform and payload technology development. It is likely that the maritime domain will exploit UXV platforms and technology developed by other domains, or adapt COTS/MOTS solutions.

B11.44 For UUVs MOD will pursue military specific technology and system integration issues that commercial operators will not address, for instance:

- Autonomous operation.
- Accurate long distance navigation.
- Power sources to support long endurance.
- High power demand sensors and data processing.
- Communication and sensor development.
- Signatures.

B11.45 Of greatest concern is the safe, rapid deployment and recovery of UXVs from ships and submarines. Concept studies will be undertaken to identify potential solutions across the fleet which, when appropriate, will be de-risked by the research programme to inform procurement decisions e.g. electromagnetic launchers.

B11.46 Collaboration is a key enabler to maintaining UK intelligent customer status and the ability to integrate UXVs into platforms. The SEAS DTC will continue to be a vehicle for exploring unmanned systems with industry and MOD will seek to strengthen its underwater vehicle work.

B11.47 **MOD will explore military application of MOTS and COTS UXVs and the integration of military payloads, utilising collaboration where possible. MOD will not invest in research into development of UUV platform architectures. UUV activity within the SEAS DTC will be strengthened.**

B11.48 **To foster innovation, MOD will continue to sponsor an annual unmanned autonomous underwater vehicle competition amongst the universities of Europe. MOD will look for an international partner, potentially France, to burden share for the next 5 years.**

Platform Systems

B11.49 MOD is now revising its Marine Systems Development Strategy, which will set a framework for investment decisions in marine systems to deliver:

- Enduring maritime platform capability through upgradeable systems.
- Deliver technology to reduce through-life costs.
- Enable unrestricted global access.
- Technology to support future surface and sub-surface platform systems architecture.

B11.50 **Power Generation and Management**. A key element of future platforms will be the generation and management of power through flexible, cost effective architectures. Whilst component technologies that deliver this capability may be developed overseas, the UK should be able to undertake platform level systems engineering e.g. incorporation of high temperature superconducting solutions, compact power sources, novel architectures, energy storage and smart systems.

B11.51 Wherever possible it is likely that marine platform system will derive from COTS/MOTS solutions. It is essential that the UK is able to understand the military consequences of this approach. For instance the UK will need to understand the battle damage tolerance of such systems and develop specific technologies to facilitate their use e.g. earth leakage detection and system reaction policies to provide resilience, and cost effective integration of software controlled COTS components into military systems.

B11.52 The Electric Ship Technology Demonstrator highlighted the benefit of collaboration (UK and France) and such opportunities will continue to be used to sustain UK intelligent customer status and, where cost effective, to develop and de-risk specific military power systems technology.

B11.53 **MOD will publish its Marine Systems Development Strategy in 2007 and through this will identify with industry the key technologies that are required to enable future military platforms. MOD will then work with industry, to explore and de-risk the integration of relevant technologies in the appropriate timeframe.**

B11.54 **Hydrodynamics.** Hydrodynamics is an underpinning technology across the maritime domain. For submarines it is an intrinsic part of safe operation thus the UK must retain a degree of technical competence in this area to predict, model and validate the manoeuvring performance of a submarine, particularly in emergency scenarios, operating at shallow depth, and when operating closely with other underwater vehicles or deploying and recovering weapons and stores.

B11.55 Hydrodynamic capabilities also provide the ability to design, assess and provide in-service support to the hydrodynamic and acoustic performance of submarine propulsors which in turn maintains the UK's ability to assess other platform propellers designed by a third party. Pursuance of hydrodynamics will involve increasing the use of computational fluid dynamics (CFD) technology potentially to reduce the UK's dependency on scale model testing. MOD will not develop CFD code where OTS packages can be adapted or modified and validated cost effectively to meet requirements.

B11.56 MOD, working with industry, will identify an effective mechanism for sustaining access to hydrodynamic capabilities. UK capabilities will be sustained through regular exercising of the submarine propulsor design and manoeuvring expertise. Close links will be maintained with the US to support UK expertise through peer review and exchange of information.

The Submarine Escape Training Tank

B11.57 Submarine Atmosphere Control (SAC). Nuclear submarines offer the capability to remain submerged for extensive periods of time. It is, therefore, vital that the submarine is able to generate and maintain a habitable atmosphere. As civil health and safety legislation develops it is essential that MOD understands issues and can develop its own safety management process in parallel to demonstrate that it is providing duty of care. This requires extensive knowledge of the contents of the submarine, their operation and potential to contaminate the atmosphere as well as the human occupational health issues.

B11.58 MOD will examine, possibly in collaboration with the US, options for SAC systems that deliver cost effective solutions for future platforms the outcome of which will be used to inform research investment by MOD and industry.

B11.59 **MOD will put in place by 2007 arrangements, which will furnish long-term provision of UK scientific capability to provide advice on submarine atmosphere control and escape and rescue to support its life support, Duty of Care responsibilities.**

The way forward for longer-term maritime technology

B11.60 It is essential that MOD and industry are aware of the technologies relevant to the maritime sector and that an understanding of the UK's technology status and the UK's requirement for onshore competence is maintained. The MIS team is exploring the product life cycle of the key maritime programmes to understand how best to sustain key UK industrial capabilities through exercising the appropriate design cycles. Exercising the design cycle at a platform level may not, in itself, identify reliably and support development of appropriate future technology. Technical Challenges, such as concept studies, offer a mechanism for identifying and developing key technologies in a coordinated and logical manner. Such challenges would be constructed to:

Maritime simulator

- Push technology boundaries with a capability focus
- Generate coherence across the maritime technology areas
- Identify key technology vital to the delivery of future maritime capability

B11.61 MOD will immediately begin work, through the MIS team, and with the industrial partners to identify suitable capability challenges that catalyse technology and an effective and affordable mechanism for introducing them.

B11.62 MOD and industry must work together to identify technology that facilitates affordable and rapid introduction of capability and both must ensure the capabilities vested in UK academia are tapped. This will require closer exposure of MOD, Industry and academic longer-term planning to identify, possibly through joint planning, opportunities of mutual benefit and ensure application of defence resources are optimised. MOD will publish its research programme relevant to the maritime sector annually and will hold regular discussions with industry and academia to foster greater understanding of each other's technological needs. Vehicles such as the Underwater Sensors Tower of Excellence will continue to be used to channel communication on specific issues and ideas but Industry and Academia must respond in kind, both through these channels and through regular briefing of MOD on their technology plans and issues.

B12 Emerging Technologies

B12.1 Emerging technologies are those distinctive new technologies that will underpin future technical capabilities. They will define the future environment in which the UK Armed Forces have to operate, can potentially redefine the way modern warfare is conducted, and may render existing capability obsolete. MOD recognises the importance of identifying these new technologies and acknowledges that there are likely to be potentially significant technologies developing within the civil sector of which it is currently unaware. MOD also recognises the need to improve our understanding of the implications of emerging technologies in order to plan for their exploitation and to rapidly develop countermeasures if necessary. Technology development is primarily driven by the civil sector and MOD needs to work effectively with industry and academia in order to identify new technologies of defence interest, react to capability developments of potential adversaries and exploit new capabilities that are generated by the combination of existing technologies.

B12.2 However, the development of emerging technologies is unpredictable with some technologies failing to deliver on their early potential, some being superseded by other developments and others successfully transitioning into innovative, new products. Therefore MOD must adopt a balanced approach to investment in emerging technologies, ensuring that it retains the flexibility to adjust its programme as required. MOD is currently active in this area but recognises the need to focus its efforts to provide a more coherent approach to the identification and exploitation of emerging technologies.

Making the Most of Emerging Technologies

B12.3 MOD recognises that in order to realise the benefits brought by emerging technologies we must be effective at bringing technologies through from identification to exploitation as shown in Figure 1. MOD's current activities in this area will be comprehensively reviewed, further developed as required and embedded over the coming months. This sub-section will provide a brief overview of the four key activities that will enable MOD to achieve this aim. More detailed proposals are being developed and will be reported in early 2007.

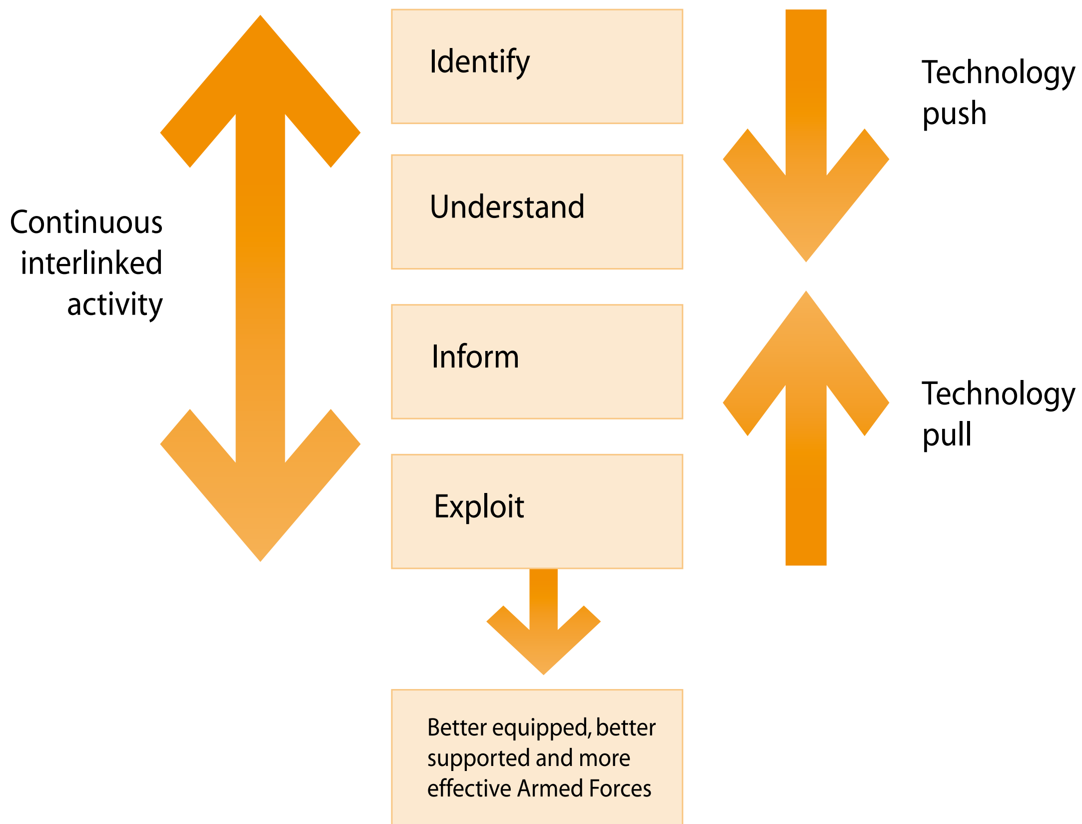


Figure 1. Key activities to enhance exploitation of emerging technologies

Identify

B12.4 In order to identify emerging technologies effectively, MOD recognises the need to undertake a number of different approaches including horizon scanning and technology watch. To improve the effectiveness of these activities MOD will enhance the cohesion between the department and other government departments, academia, industry and international bodies. In addition, MOD will establish any further activities that are necessary, delivering a co-ordinated set of complementary approaches. This will include themed workshops to explore emerging technology areas, invitations to the scientific community to submit innovative solutions to defence problems, staff secondments between MOD, industry and academia and a series of themed challenges to stimulate interest in developing new defence technologies.

Understand

B12.5 The potential defence applications of a new technology may not be immediately apparent. MOD must ensure that a sufficient level of technical awareness is developed and maintained in order that appropriate domain experts are able to understand the defence implications as the technology matures. To do this MOD will invest in technology watch activities and will review its funding structure to provide appropriate levels of support for emerging technologies. In addition this activity will enable MOD to understand what is driving the development of the technology and thus determine an appropriate investment strategy and exploitation route. The technology will also be evaluated for its potential exploitation for military use by other nations.

A view from the Laboratory

Inform

B12.6 MOD must ensure that technology recommendations are appropriately delivered to best support the key decision maker(s) in a timely fashion. Information regarding key decisions will be available to MOD stakeholders, including wider Government, industry and academia in order that interested parties can better understand MOD's future defence technology priorities.

B12.7 Ensuring that the right people are made aware of new technology is crucial to its effective exploitation. **MOD will review its processes in this area and will make specific recommendations in early 2007.**

Exploit

B12.8 A broad awareness of emerging technologies will enable MOD better to determine the appropriate exploitation strategy for any given technology both within the research programme and, where sufficiently mature, the equipment programme. MOD must develop a balanced and affordable investment in key emerging technologies while retaining the flexibility to modify its programme.

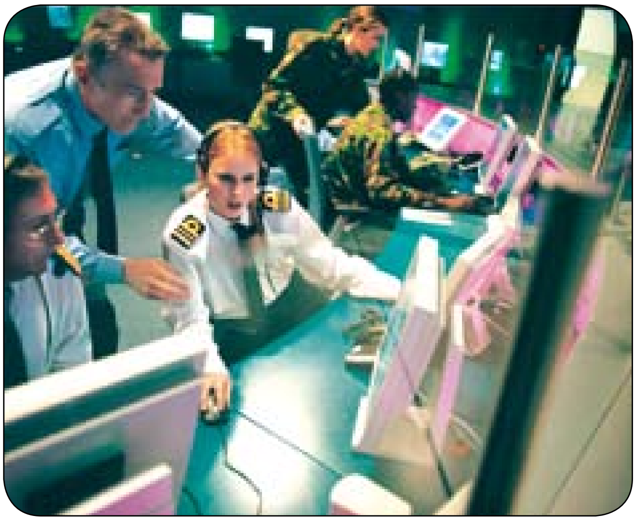
B12.9 **For those key technologies that MOD determines should be further developed, MOD will work in partnership with industry and academia and must ensure that, as promising technologies mature, they are effectively pulled through into the acquisition programme. MOD will also ensure that strategies are in place for those emerging technologies that may be used against UK Forces and must continue to invest in methods to counter such emerging threats.**

Emerging Technologies Relevant to Defence

B12.10 This sub-section details the technologies identified during a review of MOD's current corporate knowledge on emerging technologies. They have been collected from a variety of sources already known to MOD. However it should be noted that there may be significant technologies of which MOD is currently unaware, and which need to be identified. Technologies were scored predominantly on their defence relevance but other considerations - such as timeliness - were also used. Where a strategy for exploitation of the technology is in place, this has been reported.

Information and decision support

Network Enabled Capability. (Image courtesy of QinetiQ)



Battlespace Management Evaluation Centre

B12.11 Maintenance of information superiority is key to effective operations and Network Enabled Capability will underpin military operations of the future. Developments in this area will primarily be driven by civil applications, but defence specific requirements will need MOD investment. Identified technologies in the information and decision support area include:

Semantic web technologies

B12.12 The semantic web will make better use of the World Wide Web as an information source by providing computational meaning to web documents. Through developments in language technology, computers will be capable of conducting increasingly sophisticated search activities whilst ontology systems will enable computational reasoning and action. In the military context, the use of the semantic web will aid decision support by enabling the commander to retrieve the relevant information in a timely manner and have it presented in an easily understandable way. **MOD is investing at an early stage in this technology and will work with industry to take this forward. MOD currently supports research in partnership with Industry and academia through the Data Information Fusion (DIF) Defence Technology Centre (DTC) and in MOD's core research programme.**

Quantum Information Processing
Quantum computing is a concept that proposes using quantum phenomena such as superposition and entanglement to perform massively parallel calculations. Although the concept has been proved both theoretically and experimentally in principle using a technique based on Nuclear Magnetic Resonance, practical implementation remains a technological challenge. The realisation of a quantum computer holds the potential for greatly increased processing power as well as enabling computational methods that are not currently possible using conventional techniques. The defence implications were such a development to occur are significant, for example it has been suggested that such a device could render commonly used encryption algorithms redundant owing to the mathematical factorization made possible by quantum computing. Quantum cryptography could offer a potential solution to such disruption by relying upon fundamental physical characteristics of transmitted photons rather than the mathematical security offered by current encryption techniques. The advent of quantum computing would have many implications in a range of defence and security related areas including pattern recognition, networked capability and autonomy, and more generally in physics, chemistry, nano-technology and medicine.

Pervasive computing

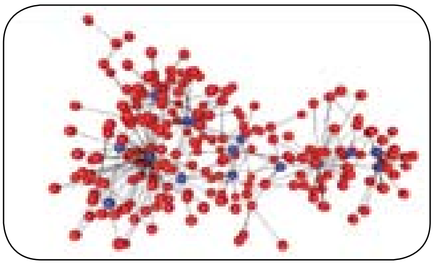
B12.13 Pervasive computing will provide relevant information and processing to the user, through the embedding of computational devices and 'smart' sensors into the environment. In the short term, highly flexible colour displays that will conform to the contours of any product or component are likely to be produced. **MOD will assume a technology watch of the civil sector and will continue to work with industry and academia through the DIF DTC.**

Identity management and continuous tracking

B12.14 In the civil arena there is rapidly growing interest in the continuous tracking and monitoring of both people and goods using a range of technologies. In defence, the main benefits of using such technologies to track people lie in their applications in counter-terrorism, such as the identification of anomalous behaviour and subsequent tracking of individuals, and in combat identification. The main defence benefit of tracking goods is, as in the civil sector, in

improved logistics. For certain technologies, such as radio frequency identification (RFID), MOD will seek to exploit industrial developments. MOD currently supports a range of activities in this area within the DIF DTC, the Electro Magnetic Remote Sensing (EMRS) DTC and its own research programme.

B12.15 One such specific technology area is the use of social network analysis (SNA) to identify network structures, strengths and vulnerabilities. This is an emerging branch of science that can be applied in many ways, for example, to identify improvements in UK networks or to best target adversarial networks through the identification of key hubs. Work is being undertaken through the Human Factors Integration (HFI) DTC, and significant expertise also exists in MOD.



Visual representation of SNA output, key nodes are highlighted in blue

Autonomous self-organised networks of sensors

B12.16 Sensor networks will be used to build a comprehensive picture of the environment, measuring a range of parameters. Such networks may take the form of intelligent "swarms" of unmanned vehicles. Three underpinning issues must be resolved before autonomous sensor networks can be fully exploited:

- Power management.
- Bandwidth availability.
- Network security.

B12.17 These issues are international in nature and concern the civil as well as the defence arena. **MOD recognises the importance of such autonomous sensor systems and ad-hoc networks to military capability and is currently funding research across the key technology areas through the DTC mechanism and other industrial interactions. A UK-US International Technology Alliance is also working in this field.**

People

B12.18 Any military operation relies upon the effectiveness of the military personnel charged with its conduct. Understanding the human system that delivers military effect, and how technology plays a part in that system is key to enabling UK Armed Forces to more effectively perform their role in any theatre of operation. This area is one where ethical and moral issues will often need to be considered alongside technological developments.

Human cognitive processes

B12.19 This area of science is involved with the understanding of the cognitive capacity of people as it changes over the life time and over generations. Specific technology developments in this area include the actual user interface, understanding user variability and understanding the level and quality of information required for optimal decision making. **MOD will invest in this area and is currently developing its strategy with respect to research investment, acknowledging the strength of the UK academic base.**

Human performance and behaviour modification

B12.20 Human performance modification is concerned with enabling people to perform at the required level for longer periods of time and mitigating for environmental extremes whilst behaviour modification typically involves altering a person's intent. Specific technologies in these areas include the development of tools for modelling human behaviour based upon detailed scientific research (e.g. heat illness). MOD is currently investing in relevant technologies predominantly through its core research programme, although other non-research programmes in MOD are also funding in this area.

RAF Harriers deck operations

Complex systems and systems integration

B12.21 A complete complex system may consist of several interacting sub-systems and one or more humans as part of the overall whole. There are two general personnel issues associated with the development and integration of complex military systems: the first involves enabling systems designers and systems integrators to understand better the potential emergent properties associated with such complex systems, including the role of the human as part of them; the second is that it is

important that MOD understands and incorporates human factors into its system designs so that personnel will be able to use, or can be trained to use, the system in a cost-effective manner.

Brain-machine interface

B12.22 The brain-machine interface describes the direct interaction between the brain and the computer in which neural impulses are used to control the machine. Recently developed for use in humans, the technologies in this area have potential military applications and MOD's current strategy is technology watch.

Bio-nanotechnology and nano-medicine

B12.23 Bio-nanotechnology is a field of nanotechnology concerned with the exploitation of the biological nanostructures that occur in living organisms. Potential applications include the production of biological materials and devices and biological sensing. Nano-medicine is the use of nanotechnology to prevent, diagnose or treat disease. Applications may include novel treatments, drug delivery and vaccine development. **Such technologies have obvious military benefits and, as a result, MOD will review the requirement for active technology watch and potential exploitation routes as specific technologies mature.**

Safer operations

B12.24 MOD has a duty of care to its personnel and is therefore committed to making the best use of technology to minimise the risks faced by the Armed Forces with the ultimate aim of reducing the number of casualties whilst retaining the ability to operate as required. In some cases new technology enables the conduct of operations that may previously have entailed an unacceptable level of risk.

Signature management

B12.25 Adaptive camouflage is a descriptive term for those technologies that can together be used to provide concealment through mimicry. Passive concealment involves the use of a physical coating with properties that enable the asset to remain undetected (e.g. photonics). Camouflage and concealment form part of MOD's overall survivability strategy and MOD is currently engaged with industry where appropriate.

Autonomous operations

B12.26 With the increasing processing power of low-cost computers there is increasing interest in devices capable of autonomous operation. The highest-profile applications are for self-driven/self-piloted vehicles of various kinds, but there are also many less obvious applications, such as systems that 'watch' areas (like sentries) for unusual or anomalous behaviour. The potential to replace people in tedious and/or dangerous tasks is very considerable, and clearly driven mainly by the many civil applications.

B12.27 For autonomous systems to be successfully deployed, developments in several technologies are required. For example, some degree of artificial intelligence will be needed by autonomous systems to allow decision making to occur without human input whilst improved machine vision will enable autonomous systems to "see" and understand their environment. In order to develop such attributes, advances in technologies such as software agents, image processing, communications, machine learning and system evolution must occur. MOD is currently investing in these technologies through its core research programme and through the Systems Engineering for Autonomous Systems (SEAS) DTC.

Generic technologies

B12.28 Some emerging technologies have the potential to underpin a wide range of military capabilities and, as such, continued awareness and appropriate investment by MOD is vital.

Portable Atomic Clocks

Until recently, the only device that could supply Atomic Clock frequency accuracy weighed several kilograms, occupied several litres and consumed hundreds of Watts of power. Recent developments have shown that such Atomic Clock capability can be delivered "on chip" in a fraction of that size and weight, consuming only milliWatts of power.

It is not widely appreciated just how critical to military equipment is the availability of an accurate frequency source. Navigational accuracy, communications bandwidth, the security level of encrypted communications, the robustness of Identify Friend or Foe systems, resistance to jamming, signal acquisition speed, the accuracy with which enemy signal sources may be located, frequency agility, etc., are all directly dependent upon the accuracy of the frequency source. Portable atomic clocks with frequency stability many hundreds or thousands of times better than the currently available quartz crystal references could significantly improve our capability in such areas and allow us to do things that we cannot currently do.

Biomimetics

B12.29 Biomimetics describes the application of designs found in nature to engineering systems and technologies. Although MOD does not currently require an overall policy on investment in biomimetics research, MOD has adopted a technology watch position and has already funded research into specific biomimetic technologies, for example through the EMRS DTC and the Research Councils' Joint Grant Scheme.

Nano-materials

B12.30 Nano-materials and nano-structures have been found to have modified properties associated with their small-scale. The impact of their application will be huge, both in the civil and the defence space. MOD has taken a technology watch position but is willing to invest in specific technology areas. MOD is currently engaged with Academia and the DTI in two Interdisciplinary Research Centres to investigate particular bio-nanomaterials and electro-nanomaterials technologies.

Advanced electronics

B12.31 Developments in molecular electronics will enable the further miniaturisation of electronic devices whilst organic electronics will provide a means of integrating electronic circuitry within structural materials, rendering a separate electronic structure unnecessary. Diamond electronics will have significant potential advantages such as eased systems integration. Diamond electronics is currently a unique UK capability held in industry and MOD is working with the industrial technology holder and academia through the EMRS DTC to develop this technology. MOD is not currently focused upon other emerging electronics areas, and has adopted a technology watch position with respect to molecular electronics. MOD's technology strategy for organic electronics will be developed.

Smart/interactive textiles

B12.32 Developments in smart/interactive textile technologies mean that there are now many potential applications of such technologies. One of these applications is in the field of human health monitoring. However, for defence purposes, human factors associated with such applications must be considered. MOD will develop a coherent strategy for this technology area in order to enable better decision making on future investment.

Capturing New Technologies

B12.33 The technologies described above are already known to MOD and, for most, strategies for their potential exploitation are in place. However there are likely to be technologies of which MOD is currently unaware. For example horizon scanning activities undertaken during the first half of 2006 have so far identified a number of technologies that could impact significantly upon future defence capability, these include the following:

Bioactive Peptides
Bioactive peptides are molecules comprising short chains of amino acids (typically less than 100). These peptides are naturally produced by a diverse group of organisms and perform a range of functions through interactions with specific cellular receptors. The pharmaceutical industry has developed many bioactive peptides for therapeutic purposes some of which have been shown to modify behaviours, a property that could have significant defence implications.

Synthetic Biological Engineering
Recent advances in genomics and proteomics will enable the engineering of biological organisms for specific tasks. For example the international Genetically Engineered Machine competition aims to address the question 'Can simple biological systems be built from standard, interchangeable parts and operated in living cells?' The use of such tailored organisms provides both military opportunities and threats.

Electromagnetic properties of meta-materials
Meta-materials are a new type of material engineered on a sub-wavelength scale to have highly controllable electromagnetic properties. These properties can include those not found in nature such as negative refractive indexes. Recent research has proposed the use of such materials to 'steer' electromagnetic radiation (such as radio waves or light) around objects. While this effect still remains to be experimentally demonstrated it could revolutionise stealth technology.

Power generation from the human body
The development of small, wireless devices for use in biomedical applications has been hindered by a lack of non-battery power technology. Recent research has shown that the mechanical energy resulting from human movement can be converted into electrical energy using aligned zinc oxide nano-wires, with an efficiency of 17–30%. This energy could be harnessed to power small devices, for example for the health monitoring of the Armed Forces.

B12.34 It is important that there is an effective mechanism through which technology developments can be highlighted directly to MOD, either by the developers of the technology or by others actively pursuing horizon scanning activities. Current methods include both formal initiatives and more informal networking opportunities. MOD will review these methods and determine whether other initiatives, such as web-based approaches, could be used to add value. It is also important that MOD reviews its current investment activities to ensure that there are sufficient opportunities to fund research and development in new technology.

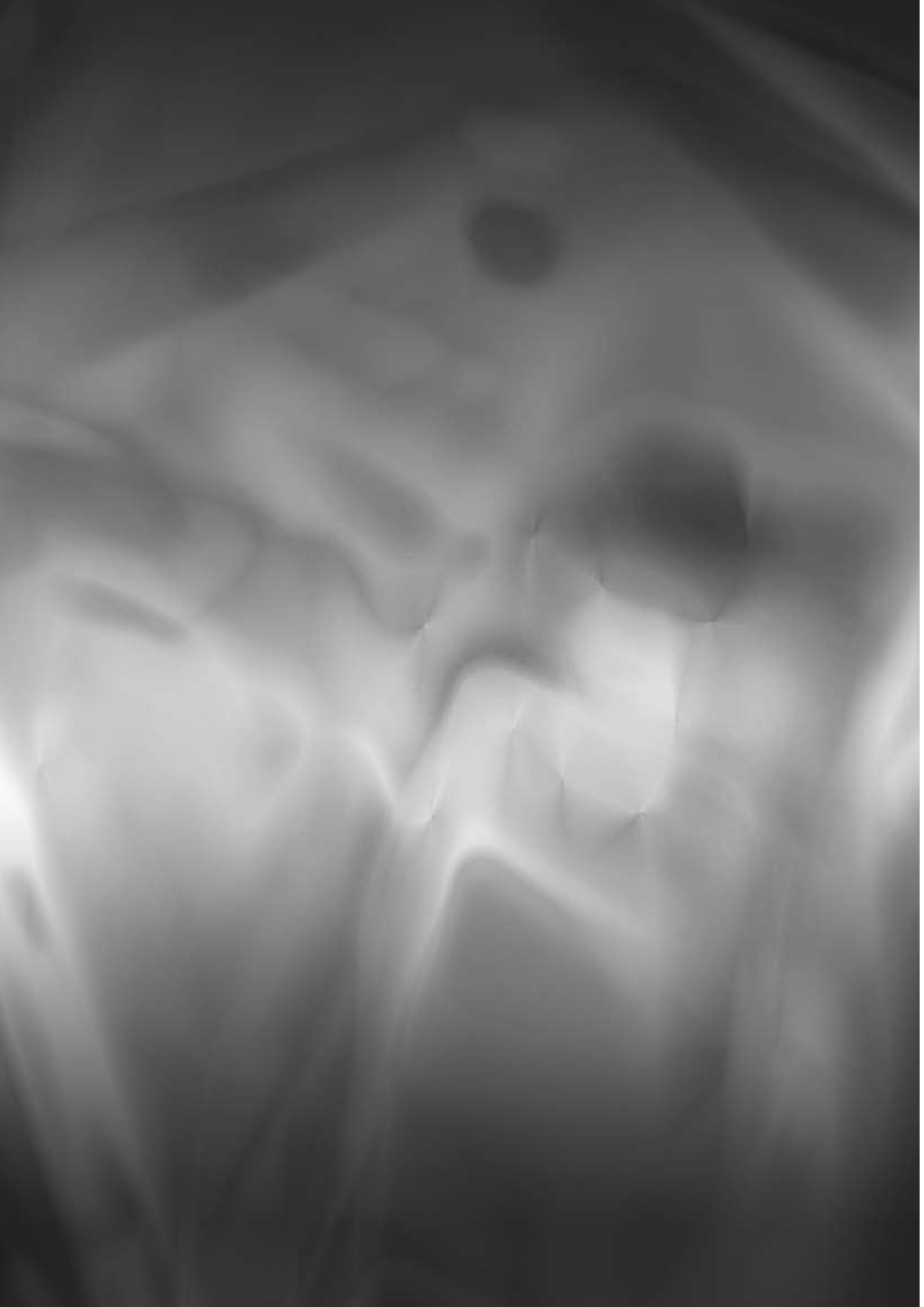
B12.35 **MOD will review its current activities regarding the identification and exploitation of emerging technologies and make recommendations in early 2007.**

B12.36 **MOD will identify effective funding mechanisms for the development of key emerging technologies.**

B12.37 **MOD will develop strategies for those technologies where an exploitation route has not already been identified.**

Taking Forward the Defence Technology Strategy

section C



C1 The Challenges

C1.1 Having highlighted the broad military capability and related science and technology challenges facing UK defence, this section details what MOD (including Dstl), working with industry, the university sector and where appropriate through collaborative partners, is going to do to ensure that science and technology plays a leading role in helping our armed forces.

Testing of titanium based alloys in turbine design

C1.2 Effective delivery of the DTS comprises 4 key components:

- Science and technology priorities.
- Delivery process to speed up research and development exploitation.
- Joint MOD/industry framework for investment.
- Working closely through Dstl and with the universities to support defence science and technology.

'In response to the wide-ranging environmental changes, the Department's strategy is increasingly changing from one of creating the Technology Base to one of accessing and exploiting it. It is focusing its expenditure on maintaining a knowledge base that covers a wide range of technologies relevant to Defence. Where the Department directly funds Defence specific technology, funding priorities are a direct reflection of the strategic and Defence value of the technology and its availability from other sources.'

National Audit Office Report: The Management of Defence Research and Technology, HC 360 Session 2003-2004: 10 March 2004

These are underpinned by 2 critical enablers:

- A well documented supply chain that stimulates and exploits innovation
- Investment in science and engineering skills of relevance to defence technologies

These are developed below.

C1.3 In delivering the defence vision[1] we must meet the science and technology needs of today, tomorrow and as far as possible in the future ensuring that we are nurturing and making best use of:

- evolutionary technology developments, to enhance and adapt existing capabilities.
- revolutionary developments to create new options and address major challenges.
- underpinning technical skills and expertise to support all aspects of defence.

C1.4 Involving many different organisations and skill-sets, within a TLCM context we will make best use of all the resources available within and to the UK. But much of the potential benefit will only be realised by these different organisations working together to mutual benefit. Accurate forecasting of TLCM depends on the systematic collection of data on all aspects of through life costs. MOD and industry must work together to create and manage these databases.

C1.5 The DIS and Enabling Acquisition Change study[2] amongst others have highlighted the need to integrate our science and technology investment, our future capability planning, the acquisition and support communities and the resources of UK industry and acedemia. Detailed priorities for science and technology investment cannot be set in the abstract, but rather will emerge from the creation and application of a joint MOD/industry planning framework strongly focussed on technology outcomes and their exploitation in defence systems. This DTS provides the necessary clarification of MOD's technology needs and priorities to enable this planning process.

[1] *Delivering Security in a Changing World – Defence White Paper – Dec 2004. The Defence Vision challenges us to be fit for the challenges of today, ready for the tasks of tomorrow and capable of building for the future*

[2] *Enabling Acquisition Change: An examination of the Ministry of Defence's ability to undertake Through Life Capability Management – dated June 2006.*

C2 Science & Technology Priorities

C2.1 Section B describes in detail MOD's view of its priorities for research and development, including those areas necessary for the UK to maintain its operational independence. A summary is provided at Annex A, key points for MOD are:

- We will continue to control all elements concerning cryptographic equipment to protect classified UK Eyes Only traffic;
- Collaboration with academia and industry to develop smaller (man-portable) biological detection and identification systems and support TDPs to de-risk potential capability solutions, **from Autumn 2006**;
- NEC is fundamental to mission success and we must be more effective than our adversaries in using and controlling information. Consequently it is essential for MOD to take the owner and leadership role in establishing a MOD/industry community of practice[1] to design and develop the defence C4ISTAR system-of-system architecture. We will develop the community of practice **by Spring 2007**;
- Radar remains our most effective all-weather, ubiquitous sensor. Hence MOD, working closely with industry, will produce detailed plans that include commercial arrangements for implementation of the existing outline strategy for radar technology and demonstration **by summer 2007**;
- A resounding message that has emerged in producing the DTS is that signal processing is a core technology where the UK is world class, and must remain so. Therefore MOD will set-up and lead a community of practice to define a national approach and roadmap on signal and data processing for defence **by Autumn 2007**.
- Building on existing work with industry (e.g. the Technology Insertion Major Programme Area) and the emerging MOD funded Software Systems Engineering Initiative to develop approaches and expertise for assurance of modular open systems establishing a framework and programme plans **by Autumn 2007**.
- Military capability will increasingly depend on technologies offering small, relatively low cost and high-precision means to define spatial and temporal resolution. MOD will therefore establish and lead a MOD/industry community of practice to develop a pan-defence roadmap for geolocation and synchronisation **by Autumn 2007**.

A portable biological detector

[1] *The concept of a community of practice (often abbreviated as CoP) refers to the process of social learning that occurs when people who have a common interest in some subject or problem collaborate over an extended period to share ideas, find solutions, and build innovations.*

- Modelling and simulation is of increasing importance, both for improved military capability and for effective application of our processes. In the latter case we need to make better use of the information flowing from the application of our processes to improve them. Consequently, MOD will lead the development of an MOD/industry framework for modelling and simulation and related data collection to support TLCM. The framework will be developed **by end 2007**.
- We will continue to work with the supply base for fixed wing propulsion, to develop exploitable technologies to improve through-life management of MOD's propulsion systems, and via novel technology approaches, address defence specific needs.
- Widening the supplier engagement in research on generic medical countermeasures starting with production of a comprehensive communication plan **by the end of 2007**.
- Support for the European and UK satellite manufacture industries to enhance our information collection and analysis to be considered for **inclusion in the 2007/08 research programme**.
- Working with the defence manufacturers and European Procurement Agencies to identify what UK investment is required to ensure that UK companies will be able to access Gallium Nitride (GaN) circuit technology within Europe **by end 2007.**
- Launch a competition, **by Spring 2007**, for a consortium to carry out research examining advances in designing, manufacturing, modelling and processing of novel materials and their use in structures that contribute to platform protection or reduce through-life costs. This will enable wide participation from both UK academia and industry and will encompass a wide area of low TRL and generic technologies.

C2.2 In rapidly moving areas of science and technology such as sensors and technologies to support C4ISTAR, we will foster and support, via the Research Acquisition Organisation (RAO), the creation of university centres of research excellence to access the knowledge of the leading research groups in defined fields. Dstl staff will work with these centres as an integral part of their activities. The first such centre will be established **by Spring 2007**.

C2.3 MOD will lead in establishing a culture of openness and joint science and technology planning and technology related risk management with industry and the universities, building on successful existing groups such as Towers of Excellence and the Defence Technology Centres. We also need to nurture those new communities of practice that have gelled during the development of this strategy. A critical dimension of this science and technology planning is the balance between military capability pull and technology push. Whilst operational need is rightly the dominant factor in defence acquisition, military requirements essential to maintain a technological lead over potential adversaries are equally technology-driven.

C3 Delivery Process To Speed Up R&D Exploitation

C3.1 A major factor that has hindered the speediest exploitation of research and development is having only a limited definition of an end-to-end process engaging all the key stakeholders. Much valuable work has been undertaken by MOD and industry on this issue. Specifically, the Technology Maturation Study[1] identified the need for Through Life Management Plans underpinned by joint MOD/industry planning and roadmapping using agreed metrics such as Technology Readiness Levels[2]. MOD will ensure that a planning process is in place involving key MOD and industry stakeholders based on technology roadmaps, to address quality and relevance using independent peer review **by September 2007**.

Training using advanced simulators prior to joint US/UK 'Red Flag' exercise

C3.2 Significant progress has been made regarding the step-by-step maturation of technologies where the scientific principles have been established and embedded within a technological approach to meet a defined military capability need. In such cases, we have set out in broad terms MOD's future approach to technology management. The DPA/DLO Technology Management Strategy[3] has developed this in more detail for the defence procurement and support communities.

C3.3 Consequently, we will build on the Technology Maturation Study findings and the MOD Technology Management Strategy that supports TLCM and embraces all stakeholders.

C3.4 The most challenging research problems facing MOD are those where there are no known solutions, or where solutions need to be more affordable and the current approach does not lend itself to significant cost reduction within the necessary performance envelope. Therefore we need to stimulate innovation for these most challenging of problems. Critical to success will be the early identification of promising approaches and termination of the less promising ones. We will drive those approaches most likely to provide significant defence benefit hard through to exploitation.

C3.5 This approach is most important when seeking solutions to the most demanding problems encountered on current operations. Good examples are the detection of IEDs in a range of difficult situations, and a number of individual and platform protection measures. MOD will make research support to operations a key component of its revised approach to delivering research (an action from the Enabling Acquisition Change[4] programme). This will include a fast-track approach to demonstrating proof of principle enabling the earliest exploitation in theatre. A description of a new research delivery scheme will be complete **by December 2006**.

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[1] Findings of the 3 Technology Maturation Study, presented at a joint MOD/industry workshop entitled 'Managing Research under Output Ownership' held on 28th May 2004 at the Defence Procurement Agency, Abbey Wood, Bristol.*
[2] http://www.ams.mod.uk/ams/content/docs/trl_guide/trlguide.pdf
[3] FBG/36/08 dated 26 May 05

[4] Enabling Acquisition Change: An examination of the MOD's ability to undertake TLMC – dated June 2006

5 Key Principles of Technology Management

(Taken from Joint DPA/DLO Management Strategy, dated 28 July 2006)

Understanding Technology Opportunities in Projects.
We will work to understand technology opportunities for our equipment project options so we enable realistic choices, through life.

Managing Technology Risks in Projects
We will *identify and manage technology risks as they apply to specific project options*.

Jointly Planning Technology Resources and Outcomes
We will *jointly plan* with other parts of MOD to optimise defence research and development resources, through life.

Equipping our Staff for the Job
We will ensure staffs are *skilled, trained and experienced* in project management, especially in schedule, risk mitigation and estimating techniques and that they have practical and successful experience of applying and developing these to the particular needs of their projects.

Industry and Teams - Working Together
We will ensure *early and effective engagement with industry*, offering visibility and dialogue on our technology plans and options, and seeking visibility and dialogue on their plans in return.

C3.6 Underpinning the entire process is ensuring suppliers are aware of defence requirements so that they can play a major role in generating solutions.

C3.7 MOD will build on its drive to keep suppliers of research informed of priorities and plans, as well as engaged in delivery based on a number of formal and informal means. For example, there is a strong ongoing need for Towers of Excellence and similar MOD/industry technical discussion fora to develop the detailed technology roadmaps and exploitation plans required to deliver against the priorities identified in this DTS. Where, as in the case of C4ISTAR, new communities of practice have evolved from work on this strategy, MOD will maintain this dialogue and interaction. Other opportunities for exchange of technology priorities and plans are provided by a range of Supplier Days, briefings and theme days.

RAO Defence Research Supplier Briefing

The move to partnering with a wider and more diverse supplier network for the non-nuclear research programme can only be successful if those involved understand and are aware of the overall structure, priorities and opportunities in the research programme. The Research Acquisition Organisation, established to define and deliver the non-nuclear research programme, holds an annual Research Supplier Briefing.

This event aims, in a single day, to provide an overview of the non-nuclear research programme highlighting the key priorities, initiatives and opportunities as well as an opportunity to network with key individuals from across the full breadth of defence research. The event has proved to be very successful attracting wide support from across industry (multinational to SME) and academia, with 450 representatives from over 130 organisations and companies attending in June 2005. With the continued expansion of research competition and the research supplier network, up to 600 people are expected on 23 November in London for the 2006 event.

Further information is available at www.science.mod.uk or from science@mod.uk

C4 Joint MOD/Industry Framework For Investment

C4.1 The DTS takes the DIS forward, giving greater emphasis to through life capability issues. Analysis has assumed that MOD will, as now, advance technologies to an intermediate technology readiness level (TRL) for the majority of topics showing significant potential. However, driving technologies through to a mature state, particularly TRL 6 and up, will require significant industrial funding.

C4.2 Against this background, the DTS is affordable provided both MOD and industry invest together, but there is much work needed on this.

C4.3 The next step is for MOD with industry to agree the principles of joint funding via the National Defence Industry Council. It will then be possible to develop technology planning on a case-by-case basis. This issue should be a major agenda item for the NDIC beginning in **Autumn 2006**.

C4.4 Resolution of this issue is critical to the UK achieving its ambitions as outlined in the DIS and carried through to this DTS.

C5 Working Closely Through Dstl and with the Universities to Support Defence Science and Technology

C5.1 Dstl is the MOD's principle internal source of scientific and technological expertise. It has a particular role in undertaking research, supporting development and giving broad science and technology advice, particularly in areas that must be retained within government.

C5.2 As such, it is vital that Dstl retains and develops the science and technology skills necessary to fulfil its role. This will be done by a combination of undertaking high quality research in-house, and in working closely with MOD's research suppliers, particularly the universities.

C5.3 Establishing the correct balance for Dstl between undertaking research to address MOD's needs and develop expertise, and gaining knowledge solely to provide advice, needs to be refined. A review to reassess this balance will be undertaken **commencing in Spring 2007**.

C5.4 Furthermore, since Dstl has a key role in helping ensure the MOD has access to skilled scientists and engineers, including supporting recruitment, it is particularly important that Dstl develops a close and effective relationship with the universities.

Electro-optic infra-red turret fitted for airbourne surveillance

C6 A Well Documented Supply Chain That Stimulates And Exploits Innovation

C6.1 A major factor affecting defence achievement of the benefits of science and technology through research and development is the stimulation, nurturing and exploitation of invention and innovation.

C6.2 Innovation in military equipments contributes to achieving a battle-winning edge by giving a technological advantage over opponents. The DIS committed MOD to develop a better understanding of the innovation process, to enable better, faster pull-through of new technology into military capability. In support of this, the NDIC (R&T) Sub-Group tasked key industrial partners to map technology trees for a wide range of military equipments. These technology trees have been produced and are providing a most useful insight into our supply chains and the contributions that different players make, further details and examples of which can be found at Annex B. The NDIC(R&T) Sub-Group will issue its innovation report examining technology trees in **Autumn 2006**.

C6.3 MOD is committed to stimulating inventive and innovative research to address the most challenging defence problems. As part of its approach MOD wishes to create a 'DARPA' like effect[1] within its R&D programme. The key characteristics of DARPA that MOD wishes to capture are the ability to stimulate potentially highly innovative and inventive ideas, and to drive the ones that show real promise hard to earliest exploitation.

Sample phials

[1] *Defense Advanced Research Projects Agency Home Page (http://www.darpa.mil/)*

Academic Engagement with Defence Research

The UK has one of the most effective and efficient science bases within the university research sector. To forge greater links with the university sector, an inaugural conference for the academic research community was held on 19 July 2006 in the Institution of Engineering and Technology, Savoy Place.

The conference was aimed at exposing all those in the academic community involved in formulation and development of research programmes to MOD's research programme and current priorities. Opportunities were outlined for working with the new Counter Terrorism Science and Technology Centre and providing greater innovation through the introduction of simplified contracting mechanisms specifically aimed at universities and SMEs.

Research Directors from the Research Acquisition Organisation (RAO) presented their current technical challenges.

Over 100 universities and research organisations were represented at the conference. We will repeat annually the Academic Engagement Conference, as well as the now regular RAO Defence Research Supplier Briefing, to continue the broadening of the research supplier base.

C6.4 This approach will enable support of more speculative and high risk basic and applied research on advanced technologies of high potential relevance to defence. MOD will produce options for achieving the DARPA effect as part of delivery of the EAC study[2] **by December 2006**.

C6.5 Ahead of a full review of how to achieve this, a scoping study is under way to cover all of MOD's R&D spend and will build on the approach adopted recently for the capability and alignment study[3] of research. These studies are crucial in benchmarking the current position ahead of defining the details of levels of funding and how to achieve the desired effect.

C6.6 However, we need not await the outcome of the review before taking some action.

[2] *Enabling Acquisition Change: An examination of the Ministry of Defence's ability to undertake Through Life Capability Management – dated June 2006*

[3] *Maximising Benefit from Defence Research – September 2006*

C6.7 A major step forward will happen when MOD puts in place a 'Competition of Ideas' process to expose and seek solutions to major defence problems that need innovation and injection of new ideas from a wide range of potential suppliers. This is expected to appeal particularly to universities, SMEs and Research and Technology Organisations, as well as other lower tier suppliers. The scheme will be operational from **Autumn 2006**.

C6.8 The initial budget to kick-start the initiative is £10m, but this will be reviewed in light of the initiative's success in stimulating novel ideas.

C6.9 MOD will also launch a 'grand challenge' competition to provide the best solution to a defined capability need. This initiative is part based on DARPA's concept[4], most recently focused on autonomous land vehicles to transit a desert terrain, with the third and latest for November 2007 addressing autonomous ground vehicles executing simulated military supply missions safely and effectively in a mock urban area. The DARPA's competitions have been very successful in both attracting many high quality research teams, and in generating innovative solutions.

C6.10 MOD's first competition will be initiated in **November 2006**.

C6.11 As part of stimulating good research proposals from across the science and technology research community, MOD is increasing the proportion of its research programme to be competed to around 60% **by 2009/10**[5].

C6.12 In addition to scientific and technological innovation, supply chains, for example those forming up around the DIS sectors, need to demonstrate innovation in business process and operation. This is very much a developing scene as each sector involving MOD and the full industrial supply chain work to make DIS a full reality. Critical to success will be to ensure the full chain, involving the critical lower tiers, for example SMEs are effectively engaged. This issue will be addressed in the NDIC(R&T) report referred to above.

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[4] *DARPA Grand Challenge website (http://www.darpa.mil/grandchallenge/index.asp)*

[5] *NAO report Management of Defence Research and Technology 10 March 2004 (note this refers to what were applied or corporate elements of the research programme which formed the QinetiQ assurance and not the whole research programme).*

C7 Investment in Science and Engineering Skills of Relevance to Defence Technologies

C7.1 The DIS[1] identified the importance of the science and engineering skills base in the UK. A recent report by the Department for Education and Skills[2] shows a steadily declining number of engineering and physical science entrants to higher education. The MOD, in partnership with industry, universities and professional organisations is committed to encouraging more students to courses of relevance to defence science and technology. We are developing two new initiatives. First we will fund an initial 1-year pilot scheme for up to 30 Doctoral studentships to be run in partnerships between Dstl, the defence industry and interested universities, in engineering and scientific fields of high importance to defence. Note that it is possible to undertake classified Doctoral degree research, and in such cases the Defence College of Management and Technology within the Defence Academy is an appropriate institution. Second we will fund an initial 1-year pilot scheme for up to 3 postdoctoral research fellowships in partnership with The Royal Society under their University Research Fellowship scheme, to attract some of the brightest and best scientists into defence and security related research. We also intend to develop a similar scheme for engineers in partnership with the Royal Academy Of Engineering. Both schemes will be reviewed after the first year to ensure their efficacy and suitability to meet MOD's needs.

C7.2 We need to have the requisite leadership, acquisition and technical skills to be able to formulate requirements, undertake and exploit R&D. To achieve better delivery of our programmes and projects and more effective TLCM, we need to:

- Ensure better alignment of skills and behaviour to business needs;
- Deepen and strengthen our science and engineering skills base to remain an intelligent customer;
- Build closer relationships with industry and the technology supply base in general;
- Work jointly with Other Government Departments (OGDs) and industry to ensure sponsored educational outreach and training programmes are co-ordinated and effective, and aim to attract students to the science, engineering and technology subjects.

C7.3 The science and technology priorities in Section B provide a baseline which allows us to profile our future science and technology skills requirement. Working as required with OGDs, industry, academia and others, we will develop plans to source, refresh and sustain these skills by:

- Developing mechanisms to measure science and technology related skills across the defence community;
- Developing/employing Government and industry wide standards to ensure effective comparisons can be made across the defence community;
- Co-operating with the other DIS workstrands addressing capacity and demand within the industrial supply chains to identify and address relevant science and technology related skills shortfalls;
- Identifying and addressing common challenges (e.g. demographics and the proportion of students opting for science and engineering courses);
- Identify and encouraging best practice in educational outreach and training programmes.

C7.4 Under the people and skills area we will:

- Launch an initial 1-year pilot Doctoral research scheme (reviewed after the first year) to be run in partnerships between Dstl, the defence and technology companies and interested universities, in engineering and scientific fields of high importance to defence, to support up to 30 students from **Summer 2007**;
- Work with the Royal Society in a 1-year pilot scheme (to be reviewed after the first year) to identify candidates for up to 3 postdoctoral research fellowships **by Winter 2006**;
- Develop the bilateral engagement with industry, through the NDIC (R&T) and Human Resources sub-groups, to develop a joint MOD and industry R&D Skills programme **by Spring 2007**;
- Support the Defence Acquisition Change Programme (DACP) People Programme to ensure a critical review of our need for professional skills in science and engineering, with supporting career structures **by end 2007**;
- Develop an initial Skills Growth Plan to identify the professional skills gaps in science and engineering skills across MOD **by Autumn 2006**;
- Carry out a complete analysis of science and engineering skills, building on current work to define career frameworks to enable professional development and inform training and development plans, define professional standards using competence frameworks, skills "footprints" and the requirements for accomplishments such as licences **during 2007**.

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[1] *DIS, Section B1 xvi ff.*

[2] *The Supply and Demand for Science, Technology, Engineering and Mathematics Skills in the UK Economy, Research Report RR775, 2006.*

C8 Summary

C8.1 Underpinning the science, research and development elements of the DIS, this update of the DTS is a major step forward, explicitly detailing MOD's agenda for change to:

- Deliver an affordable technology strategy to meet our capability needs, within planned MOD funding allocations, subject to the right apportionment of costs between MOD and industry;
- Help ensure the right calibre of people and skills are available to deliver this strategy;
- Sustain vital defence technologies in the appropriate areas of the technology supply chain.

C8.2 In it we have identified:

- The need to sustain vital defence technologies in the long term by harnessing all parts of the R&D chain through government, industry, academia and where there is mutual advantage with our key allies;
- The need to develop a coherent structure and process to ensure research requirements are drawn up and actioned effectively;
- The need to create structures within the R&D programme that are capable of flexible and rapid responses to the changing defence environment and processes that allow rapid technology insertion;
- The need to build on existing and develop new joint working practices to fulfil and deliver the R&D programme and to pull through the fruits of our R&D into world class military capability;
- MOD's strategic vision of the UK's defence R&D requirements over the next 10 years;
- Those priority science and technology research and development areas critical to our national interests and security, areas where our needs can be met through collaboration;
- Those areas that will underpin our Through Life Capability Management;
- The need to invest in science and engineering skills.

C8.3 This is not an end state in developing the DTS; we will ensure progress is regularly reviewed by the Chief Scientific Adviser, the Acquisition Policy Board reporting to the Minister for Defence Procurement, the NDIC (R&T) sub-group, and the DSAC.

C8.4 The task we now face is to build on this planning bedrock. We recognise that taking the DTS forward will require some tough decisions including the fraction of MOD spend that is assigned to R&D, but by working together this ambitious agenda is both deliverable and affordable. We must not evade these decisions as our future military capability, the competitiveness of UK defence industry, and the strength of the UK R&D base depend on it. Together we will rise to this challenge. Our armed forces and our nation deserve nothing less than our very best endeavours to meet the demanding tasks defined in this report. In order to succeed we will need the full support and engagement of both industry and the universities.

C8.5 We are most grateful for all the help, inputs and council received in the production of this DTS from across MOD, industry and academia; we now look forward to working with you all in its delivery.

Summary of Defence Priority Technologies

Function	Priority Technologies	Technology Supply Route: Sovereign	Technology Supply Route: Collaboration
Cross-Cutting Technologies (Section B.2) and General Themes			
Campaign, Ops, Mission planning & management, Battlespace Management	Assessment, decision support, situational awareness, delivery, interface, date utilisation, risk and asset management tools	Requirements definition, intelligent customer, experimental and assessment, data fusion and utilisation, understanding of interfaces and algorithms.	Implementation of algorithms
Concepts, design & integration	Systems and platform integration, assessment tools	Design, safety assurance including maritime and airworthiness	Validation tools, integration
Simulation, Modelling, Acceptance, Certification & Assurance	TLCM and synthetic systems/environments modelling, affordable assurance, design, interface specifications. Performance modelling, Support to Operations.	Access to skills, intelligent customer, methodology.	Exploiting collaboration in various areas.
Processing and RF technologies including transmit/receive modules	Leading-edge processing techniques and technologies including certain manufacturing capability	Research, design, develop, modify, maintain and test, manufacture and integrate technologies into radar systems	Technology development/ maturity. Compact RF payloads for tactical surveillance
EO and other Sensors, EO Protection Measures and Counter-measures	Higher performance detectors, protection devices and maximising innovation to generate novel exploitation approaches.	Capability to design, evaluate, manufacture and integrate into systems	Beam control technologies, and UK access.
Uninhabited systems	Power sources, autonomous control capabilities, sensors, modelling, integration and certification	Autonomy, intelligent customer, design development and cost–effectiveness assessment, access, integration	Power sources, implementation of autonomous decision making algorithms, UAV platform and interface specifications
Electronic Warfare	Systems, processes and manufacturing capabilities in surveillance (ES), attack (EA) and defence (ED) across all environments and range of platforms including C4ISTAR	UK national capability to research, design, manufacture, programme, supply, integrate, test and evaluate and optimise performance. Intelligent customer status.	

Function	Priority Technologies	Technology Supply Route: Sovereign	Technology Supply Route: Collaboration
Signal Processing	Novel/ advanced techniques and capabilities	Ability to research, design, evaluate, exploit and integrate advanced signal processing algorithms into systems	Possible whilst maintaining UK capability advantage and control of our sensitive systems
Secure & Robust Comms and Information Management	Areas of manufacture, test & evaluation, certain algorithms, network capabilities, modelling, assurity and technologies	Intelligent customer across a range of capability areas	Interoperability aspects.
Human integration and interoperability	Human[1]/cognitive/ technology dimension of interpretation and exploitation of shared awareness.	Cognitive models, aircrew survivability	Understanding of human performance and behaviour. Effect of drugs on performance. Technology Watch. Cross-cultural issues. Duty of care issues.
Training	Embedded and collective.	Intelligent customer, specifications, test/ assessment. Bridging the gap between man-in-loop models and large scale OA simulations.	
Integrated Survivability	Systems engineering approach, design and modelling, solutions, threat assessment.	Assess, design and understand survivability technologies. Design authority and/or capability of key systems, deep understanding of current and emerging threats.	Access to tools, skills and technology.
Power source and supply technologies	Power management, reduced power demand and power sources including low weight , high energy density, portable power systems.	System design, exploitation of civil developments and technologies to support through life ownership.	Technology watch.
Advanced materials	Low observable and advanced materials, smart materials, modelling.	Design, support for ceramic armour, manufacturing, integration, modelling and exploitation.	Exploitation of smart materials. Supply chain for specialist steels. Technology watch.
Open Systems & Architectures	Design, integration, test and evaluation.	Own, maintain and where necessary develop standards. Control of certain platform architectures and interfaces.	
Electronics Hardware	Obsolescence and systems reliability.	Intelligent customer and user.	Access.
Geolocation and Synchronisation	Atomic clocks, position measurement, interoperability.	Access to technology, ownership of designs and standards.	

[1] *Research involving human participants undertaken, funded or sponsored by MOD must meet acceptable ethical standards. Ethical standards are upheld by the MOD Research Ethics Committee..*

Function	Priority Technologies	Technology Supply Route Sovereign	 Collaboration
Platform supportability	Availability and supportability technologies.	Platform specific.	Platform specific.
Logistics	Wide range of environment-specific technologies.	Intelligent customer.	
C4ISTAR (Section B.3)			
Shared Situational Understanding	Data management, standards, calibration, situational awareness and collation technologies	Algorithms.	Standards, methods of sensor calibration, metrics and measurement techniques. Common data sets.
Collection Co-ordination and Information Requirements Management (CCIRM)	Assessment, decision support, situational awareness, delivery, interface, date utilisation, risk, asset management and tasking information track tools	Algorithms, processes and understanding of equipment interfaces and capabilities.	Implementation of algorithms.
Collaborative distributed and co-located working	Leadership and information sharing technologies.	Exploitation of commercial products.	Tools and information sharing technologies.
C2	Adaptive, HQ effectiveness and audit tools	Exploitation of commercial products.	C2 tools.
Communications and radar surveillance	Detection, prosecution and location capabilities and UAV payloads	Prototype demonstration.	Optional route.
Active EO/IR, Multi-spectral and Hyper-spectral imaging	3D terrain model collection and target geolocation, optical design, detector/filter cold shield and smart focal plane processing techniques		Terrain model collection techniques and target geolocation and all associated with Multi-spectral and Hyper-spectral imaging.
Acoustic sources	Under water based - contact payloads for survey and reconnaissance. Ground – unattended sensors.	Underwater - ability to demonstrate TRL 6 maturity. None.	Optional route. Unattended ground sensors.
HumInt	Behaviour prediction and mental models	Sense and predict human behaviour.	Mental models.
Cyber	Network, monitoring, analysis, integration and data fusion technologies	Prototype demonstration when no COTS/tailoring.	Case specific technologies.
Meteorological, oceanographic, hydrographic	Optimising data collection.	None.	Optimisation methods.
Non-traditional and open sources	Integration	Integration.	Annotation with appropriate metadata.

Function	Priority Technologies	Technology Supply Route: Sovereign	Technology Supply Route: Collaboration
Networked sensor control, management and cueing	Use, understanding and integration technologies	Algorithms, understanding of equipment interface.	Implementation of algorithms.
High altitude platforms	Design and integration	None.	All.
Small satellites	Design and integration of satellite and payloads, C2 systems and data reception	Payload integration.	Procurement of satellite bus and payload.
Data fusion, mining and reduction	Characterisation, processing and management.	Algorithm design, modification and integration into UK equipment.	Implementation of algorithms.
3D target geolocation	Sensors, accuracy improvements and geolocation processes.	Algorithm design and the skills and knowledge to modify and integrate into UK equipment.	Implementation of algorithms.
Automatic target detection/recognition, and positive identification	Target and background modelling, simulation and processing. Sensor performance modelling. Imagery Classification and emitter identification.	Algorithm design, modification and integration into UK equipment.	Implementation of algorithms.
Battle damage prediction/ collateral damage estimation	Effects prediction, assessment and recording.	Algorithm design, modification and integration into UK equipment.	Implementation of algorithms.
Image exploitation and translation/cultural awareness	Processing and recognition technologies.	Algorithm design, modification and integration into UK equipment.	Implementation of algorithms.
Satellite communications	Robust, secure telemetry, tracking and control, dynamic bandwidth allocation and high bandwidth optical (laser) links.	Robust, secure telemetry, tracking and control.	Dynamic bandwidth allocation, high bandwidth optical (laser) links.
HF, VHF & UHF comms	Software defined radio, waveform design and integration, self-organising nets, IP over HF, cognitive radio.	Waveform design and integration.	Software defined radio, self organising nets, IP over HF, cognitive radio.
Broadband wireless networks	Interference suppression and interoperability.	None.	Interference suppression, interoperability.
Tactical data links	Size/weight/volume reduction, plus various process, capabilities and technologies.	None.	All.

Function	Priority Technologies	Technology Supply Route: Sovereign	Technology Supply Route: Collaboration
Waveform design, spectrum and bandwidth management	Technologies and management, plus UK eyes only cryptographic techniques.	Ability to integrate certain techniques into capability. Implementation of UK eyes only cryptographic techniques.	Synchronisation schemes, coding schemes, modulation techniques, smart spectrum usage. Integration of information management with spectrum management.
Network information distribution layer and mobile / ad hoc / dynamic networks	High assurance internet protocol encryption (HAIPE), auto-configuring, self healing and scalability.	UK version of HAIPE.	UK/US collaboration on HAIPE specifications plus all others. Auto configuring, self healing and scalability for large numbers of users.
Operating Systems (OS)	Design and operation understanding OS, test facilities.	Design understanding and operation; test facilities.	To meet MOD's needs.
Cryptography	HAIPE, Secure Comms Internet Protocol, disk encryption, software and programme crypto, key management and chip design.	All.	International specifications.
Computer Network Defence	Intrusion detection systems and protection, sensors, analysis, reaction, denial of service prevention.	All.	None.
Secure Information Exchange Techniques	Critical technologies.	Message sanction and release techniques, digital signatures.	Guards, one-way diodes, labelling and tagging.
Identity management / access control	Critical technologies.	None.	Biometrics; RF ID, PKI credentials, smart cards.
Information presentation	Information extraction and presentation.	Tailoring of COTS.	Commodity items.
Knowledge stores and repositories	Information handling technologies, high speed IO.	Tailoring of COTS.	Information search, tagging and representation technologies.
End-to-end network, information and security management	Appreciation, various networks, data and security management technologies.	Methods of managing commercial and military networks, all security aspects.	Understanding the problem and interoperability.
Close Combat and Combat Support (Section B.4)			
Mounted Platform Systems	Battlespace Management Systems, key technologies, EMP/EMC, Survivability.	System design and integration.	
Soldiers Systems Platform Integration	Physical, electronic and human systems' architecture.	Design, integration, specification and assured access.	
Lethality	Various weapons systems and ammunition types.	Intelligent customer, integration, T&E.	

Function	Priority Technologies	Technology Supply Route Sovereign	 Collaboration
Mobility and Structures	Electric drive and other key elements, novel structures.	Intelligent customer, integration, T&E.	
Counter-mine, gap-crossing and counter-mobility systems	Systems, sensors and neutralisation.	Specification, prototype design, integration and T&E for gap crossing and counter mobility systems.	Specification, prototype design for sensors, intelligent customer status for neutralisation of mines.
CBRN (Section B.5)			
Hazard assessment & management, detection, identification, T&E	Broad range of characterization, sampling, detection, diagnostic and testing technologies.	Understanding of agents, rapid detection and identification technologies including "stand off", decontamination technologies, exposure levels, development of algorithms.	Dispersal understanding, command and decision tool, access facilities, development of common standards for equipment.
Physical protection	Materials, physiology and filtration.	Design, development and understanding.	Limited areas where appropriate.
Medical counter-measures	Range of medical and clinical technologies.	Knowledge, access, application, design and development.	Limited areas where appropriate.
Counter Terrorism (Section B.6)			
Notwithstanding the sensitive nature of its CT programmes, MOD will seek earlier engagement with key List X suppliers including SMEs and academia to support these niche areas.			
Complex Weapons (Section B.7)			
Software	Key functionality.	Design, develop and understanding.	
NEC	Datalinks, comms, crypto and integration.	Understanding.	Share experience.
Propulsion, aerodynamics and airframes	Range and propulsion technologies.	Design, modelling, manufacture, integration and understanding.	Composite case technology and composite propellants.
Payload / effects	Conventional, DEW and non-lethal technologies.	Critical safety, integration, design and assessment.	
Survivability	Stealth and countermeasures.	Design, understanding and assessment.	Sub-system research, sensor hardware.
General Munitions And Energetic Technologies (Section B.8)			
Design and performance	Intelligent design, Integrated Modelling, effects and its modelling.	Integration, certification, understanding, design and test.	Open architecture designs, obsolescence, modelling.
Safety and ownership	Insensitive Munitions and Munitions safety, monitoring, disposal, T&E.	Understanding and ownership tools.	Various IM aspects, disposal, access to T&E facilities.

Function	Priority Technologies	Technology Supply Route	
		Sovereign	**Collaboration**
Pyrotechnic stores	IR and RF Countermeasures.	Design, development, assessment and manufacture capability for air platform expendable IR and RF decoys.	
Energetics & Energetic Materials	IM aspects, smart initiation, modelling, Material Characterisation, T&E.	Understanding, design, testing and development areas.	Underpinning S&T. Access to non-UK materials and components.
Fixed Wing, UAVs And Helicopters (Section B.9 and B.10)			
Low Observability	Various signature and its manufacturing technologies	Intelligent customer, integrated design development and cost effectiveness assessment.	
Propulsion, Aerodynamics, Structures and Control	Performance monitoring analysis, and technologies to support through life performance.	Intelligent customer status and technology watch.	Engine supportability.
UAV	Autonomy, prototyping, enterprise and economic models.	Airworthiness, design, development and assessment, T&E.	Approaches to regulations of UAV operations in controlled airspace.
Helicopters	Operational and capability assessment, design, airframes, rotor systems, vibration, noise and power management, survivability, sensors, mission systems	Design, develop, evaluate, integrate and understanding. Intelligent customer status.	
Maritime (Section B.11)			
Survivability	Submarines acoustic materials and structures, non acoustic signatures	Design, development, systems integration, testing, manufacture and through life capability management	Collaborate with US to maintain national expertise. Test facilities may be obtained overseas.
Combat systems	Torpedo defence, sonar	Threat analysis, design & development, test & evaluation, integration	Collaboration to be exploited where appropriate, e.g. maintaining intelligent customer status for sonar systems and facilitating interoperability.
Platform	Power, hydrodynamics, submarine atmosphere control	Intelligent customer, design, development, and in-service support for quiet submarine propulsions and atmospheric management technologies, duty of care	Test facilities, information exchange

1. The NDIC R&T subgroup is leading work to better understand innovation in the supply chain. In support of that work industrial partners have mapped technology trees for a wide range of military equipments. This annex is based on early findings from that work.

2. A technology tree is a hierarchical diagram which breaks an equipment down into its contributory elements, starting at systems level and working down through sub-systems to underlying technologies. For this exercise, suppliers were identified at each level in each tree. Information was also gathered on the nature or role of the supplier (large company, SME, RTO[1], or University), their geographical location (UK, US, EU, etc) and on the extent to which the product supplied was innovative through a simple classification (COTS, MOTS, bespoke, ongoing development, or innovative).

3. A total of 36 technology trees were produced which, although not constituting a comprehensive dataset in all areas of capability, provide some useful insights about the supply chain and the contributions different players make. However, whilst technology trees give a snapshot of the supply chain for the end product, they tell us little about the process or mechanisms of innovation *per se*. For the purposes of this document and to improve readability and clarity the completed trees have been edited to highlight the innovative elements and simplified to round up those 'branches' without specific innovative elements.

4. To understand how innovation happens we need to know how the technologies were developed for a given equipment; this requires a case history to supplement the information in the tree. Such accompanying narratives were also collected where possible.

The Role of SMEs in Innovation In Defence

5. SMEs typically are niche suppliers of particular materials, products or services, which lie outside the span of the major prime contractors. A major source of SME involvement in innovation is in the form of "spin-off" ventures, either from the University sector – where they provide a knowledge transfer mechanism from academia to industry – or from major companies – where individuals set up on their own to take forward an idea.

6. In some equipment sectors, however, SMEs enjoy a greater degree of success. Where there are immediate capability gaps and operational requirements lying outside the mainstream activities of the major Defence contractors, and where the scale of procurement is more limited, SMEs are very much to the fore – notably in the CBRN and Counter-Terrorism spheres of activity. An important characteristic of the latter sector in particular is a greater emphasis on short-term procurement (against Urgent Operational Requirements, for example). This is an area where the flexibility and responsiveness of SMEs comes into its own – they can play to their strengths

7. The technology tree for the 2193 Mine Hunting Sonar illustrates the role of SMEs and Universities in innovation for small-scale equipments. All of the SMEs involved were niche suppliers of specialised sonar technology elements. In other trees involvement is more limited but still of value.

2193 Mine Hunting Sonar Technology Tree

Brought into service in 2005, 2193 is high-frequency active sonar manufactured by Thales and installed on Hunt class mine countermeasures vessel. It is a highly innovative design and can detect mines with small acoustic signatures at depth. The technology tree reveals the involvement of four niche SME suppliers of specialised sonar technology elements, and two universities under a programmes led by DERA (now QinetiQ) Winfrith.

Development was driven by DERA working with the Universities and SMEs in question. Although innovative in a number of respects, the most ground-breaking innovation was the invention and use of 1-3 composites in the sensor (hydrophone). These materials were developed by Strathclyde University and are comprised of piezoelectric ceramic pillars embedded in a polymer matrix, giving the hydrophone a unique wideband response and sensitivity. The SME materials supplier is a spin-off venture from Strathclyde University, including a member of the original academic research team as a key player.

[1] *Research & Technology Organisation*

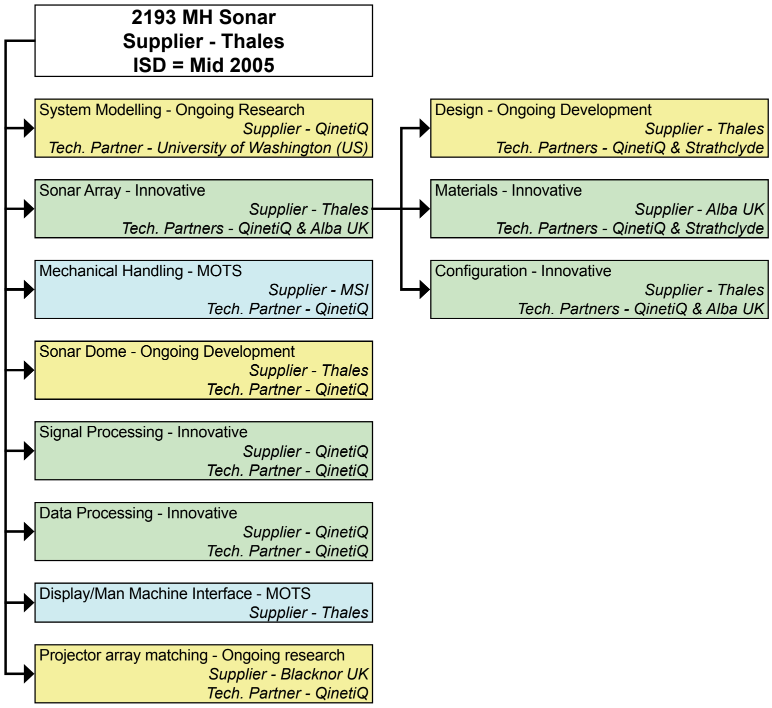

Fig 1. Sonar 2193 Technology Tree

The Role Of Academia In Innovation In Defence

8. All innovation begins with creative ideas[2], and there is no shortage of knowledge or of the skills of invention in the United Kingdom. A recent HM Treasury study attests to the fact that the UK has a world-class science and engineering academic infrastructure; we remain second only to the US in global scientific excellence, as measured by citations[3].

9. The HM Treasury Lambert Review on business and university collaboration established that a new trend is reshaping the way companies undertake research and development[5]. It identified that companies are moving away from a closed approach to innovation in which most of their research and development is controlled and done in-house, to one in which they are actively seeking to collaborate with others.

10. The view from academia is that progress has been made since the Lambert Review; however more can be done to improve the transfer of knowledge and technology between universities and businesses. It seems that the best technology transfer has come through exchanges of staff, particularly through the secondment of industry personnel to universities. The contacts and industrial perspective that these industrialists bring can be invaluable.

11. Technology trees can give some indication of the role of academia, however, the principle conclusion is that the extent of University involvement in particular is under-represented in the current set of trees, because their involvement is only exposed at the very extremities of 'complete' trees, or in associated narratives; whereas, many of the trees do not extend this far down the supply chain hierarchy.

12. A distinction must be made between equipment procurement-led involvement of the Universities, as described above, and their involvement in longer-term research through the MOD Research Programme, Defence Technology Centres, and Towers of Excellence. In those cases, the linkage to the equipment supply chain is more tenuous, as the Universities are not undertaking research aimed at supporting a specific requirement; but emerging technologies are expected to find their expression in future (as yet unspecified) military capabilities.

13. The following technology tree, produced by Selex Sensors and Airborne Systems Ltd, highlights the inherent role that academia plays when we investigate the underpinning science and research programmes that support generic capability areas.

The Role Of Larger Industry and RTOs In Innovation In Defence

14. The first main conclusion which can be drawn from this work is that innovation in major military procurements is both customer driven in the form of military capability pull or requirements-led and opportunity driven where advances in science and engineering provide new solutions. Except where there are very substantial export or other wider (dual use) market opportunities, industry tends not to invest in the development of new military equipments. In common with a wide range of complex products and systems

[2] *Luecke and Katz (2003), Managing Creativity and Innovation, Harvard Business School Press, pp1154-1155*
[3] *HM Treasury, Science and Innovation Investment Framework 2004-2014: Next Steps, 2006*
[5] *HM Treasury, The Lambert Review of Business-University Collaboration, 2003*

(CoPS)[4], military equipments tend to be technologically complex, produced in small batches, on a project-managed basis, with continuing innovation through life and with substantial customer involvement. This is in sharp contrast to classical market-led innovation, where entrepreneurs look to produce relatively straightforward, novel products in large numbers to sell to a mass consumer market, with no customer involvement in their development. In military procurement, most equipments are not purchased in sufficiently large numbers to be mass-produced, and Government is the customer, meaning that product development cannot sensibly

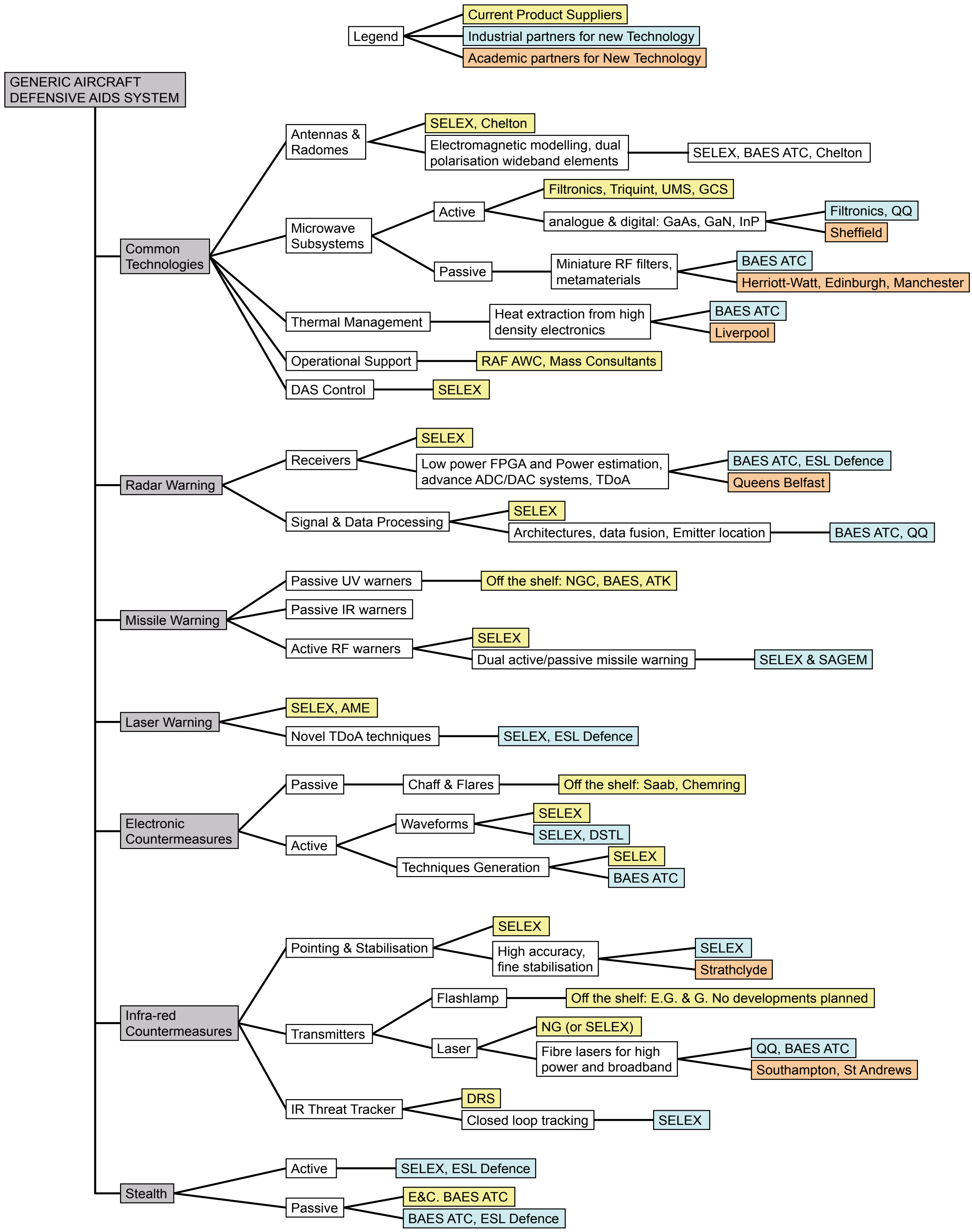

Figure 2. Generic Aircraft Defensive Aids Technology Tree

[4] *Hobday, M, "Product Complexity Innovation and Industrial Organisation", Research Policy 26 (1998), pp 689-710*

be taken forward in isolation from the customer. The requirement is therefore all-important.

15. Whilst operational need is the dominant factor in defence procurement, military customer requirements are in no small part technology-driven, precisely because of the need to maintain a technological lead over other nations. The emergence of new technologies presents opportunities ranging from incremental improvements in capability, to fundamental (disruptive) changes in the nature of future warfare, as well as generating new threats from potential adversaries. The translation of technology opportunities and threats, through concepts, into requirements, is an essential customer-driven step in the innovation process. The requirement is the key driver for taking technology from laboratory proof-of-concept through to mature equipment for manufacture. Equally important is customer commitment to progress delivery of technology (working with industrial partners) against such requirements. Crucially, these two elements together enable the ' valley of death' between laboratory proof-of-concept and manufacture to be bridged.

Challenger 2 battle tank on exercise in Oman

Challenger II Main Battle Tank Technology Tree

Challenger I was acquired as a product by Vickers (now BAE Systems) in the 1980s from Royal Ordnance and had recognised shortcomings. Vickers saw an opportunity to improve it, mainly by substituting a modern private venture turret. Other improvements included fitting a gun with independently stabilised directional sights and an improved transmission. Challenger II was then offered in competition against the US M1A2, German Leopard, and French Leclerc tanks. In contrast, the contractor's proposal to introduce a new engine management system based on a MOTS solution used in helicopters was rejected in favour of the existing MOD-sponsored design. Challenger II offered several other innovations, notably new armour which had been incrementally developed by DERA (now DSTL) to meet the long rod kinetic penetrator threat. The TO Gunnery Sight, although bought as a military off-the-shelf (MOTS) equipment, utilised the TICM II (Thermal Imaging Common Module) which emerged from a QinetiQ Malvern research programme, with the involvement of universities and SMEs.

Challenger II's novel hydro-pneumatic suspension system, which enabled it to travel at higher off-road speeds than most of its competitors, was developed under contract placed by MVEE (now QinetiQ) with an SME (now Horstman). It was a long-standing MOD research programme to improve the design of the tank, spanning a range of research disciplines. Substantial impetus was given by the sponsorship of an export customer and the technology moved very quickly.

This programme was also the first armoured vehicle to use a data bus, resulting from QinetiQ research on vehtronics and crew systems. Crucially, this allowed BAE Systems to select component sub-systems from different suppliers.

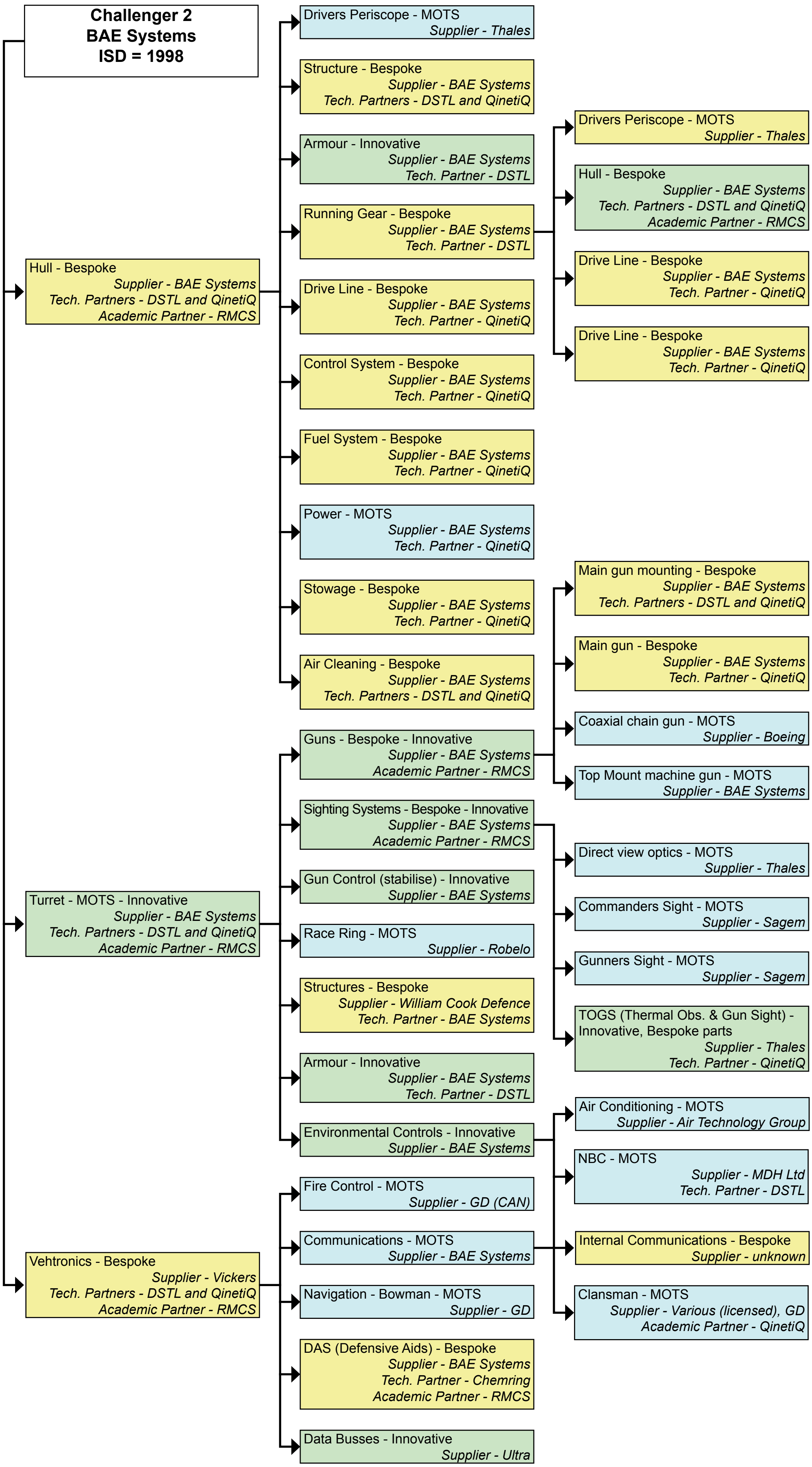

Fig 3. Challenger II Technology Tree

16. Research and Technology Organisations (RTOs) may span the whole range of activities from applied research to development of technology demonstrators or even production (in some cases) of high-technology equipments. They can take the role of academic partners or new technology partners. Examples range from QinetiQ and Roke Manor in industry, to the in-house provider Dstl in MOD. However, the distinction is somewhat artificial, as the major Prime contractors have their own in-house capabilities who provide the same service (e.g. research arms of BAES for Industry), albeit in a relatively limited number of R&T areas as appropriate.

17. Looking at the Technology Trees, we see clear evidence of RTO involvement, and the RTOs are well-represented, as they are typically involved in activities slightly further up the the supply chain hierarchy than the University sector.

Airborne Stand-Off Radar (ASTOR) Technology Tree

ASTOR, which entered service in 2005, is a high-resolution synthetic aperture radar and ground moving target identification radar mounted on a militarised civil aircraft. ASTOR images the battlefield and tracks targets in all-weather conditions, day or night, over a large area. It gives early realisation of some NEC principles through its ability to share data with other reconnaissance assets (RAPTOR and JSTARS). Examination of the ASTOR tree shows that it is supplied by a US prime contractor and not surprisingly, therefore, most of its component systems are US-sourced, giving the impression that ASTOR owes its cutting edge to innovative US technologies.

However the US prime won the competition to manufacture ASTOR working to a UK requirement which drove the prime to adopt innovative design principles. Although the extent of their contribution is not obvious from the technology tree, DERA (now QinetiQ) drove much of the innovation in their role as the research and technology partner, including the dual-mode radar and dual signal processing, the active array of transmit and receive modules, and the motion compensation algorithms (which were produced in Malvern). QinetiQ's contribution was the result of long term research, the CASTOR programme, which in part shadowed similar US research (U2 ASARS, JSTARS) and expertise provided by its long-standing centre of excellence for radar technologies.

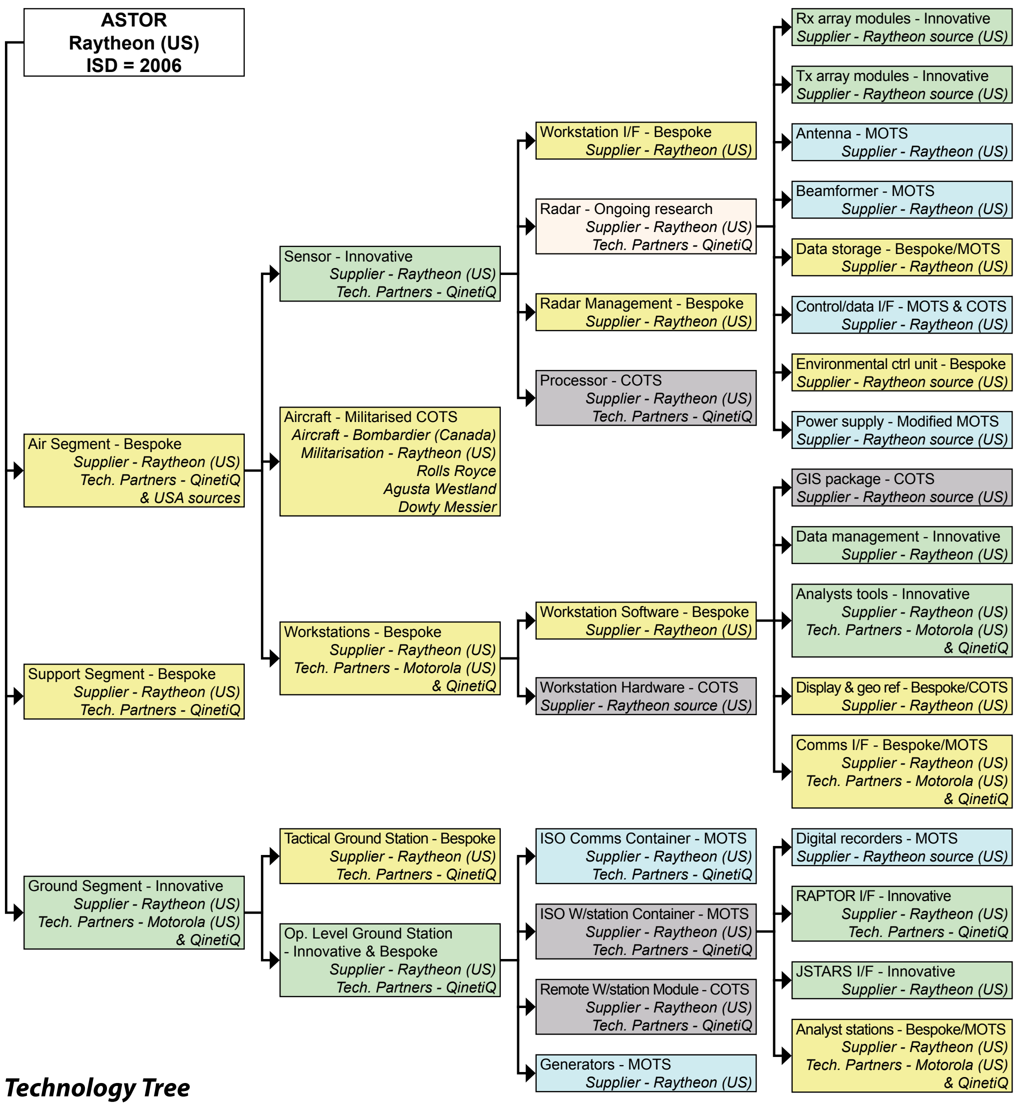

Fig 4. ASTOR Technology Tree

18. The second main conclusion is that world class military equipments currently in service owe much of their success to innovative science or technology which is the result of carefully targeted, long-term military investment in R&D. This represents a realisation of the importance of 'technology-push'. This underlines the need for long-term commitment to selective MOD funding of R&D.

19. Implicit in the above discussion is the existence of a technology 'conveyer belt' that progresses technology through the full range of TRLs from blue-skies research through to equipment manufacture. Historically, that conveyor belt was fed by the MOD's Research Establishments (REs), with industry becoming involved through competition at the technology demonstrator and manufacture phases. Some of the Technology Trees for world-class equipments currently in-service are testimony to the success of that process. With the privatisation of the REs, future increased outsourcing of Defence R&D to a wider market, and the advent of SMART procurement – all of which are positive developments – there is a need to examine how the 'conveyor belt' now operates, how effective it is, and how it can be strengthened to speed up technology pull-through, to tauten delivery against customer needs, and to assure the coupling mechanisms into SMART procurement processes.

20. However, innovation in military equipments not only contributes to battle-winning edge by giving a technological advantage over opponents, it also gives UK Defence industries a competitive edge in the export market. In the absence of a specific military requirement industry may be reluctant to invest in the development of new military technology. However, it is quick to seize the opportunity to capitalise on its investment when it has successfully developed a new equipment in response to a requirement. So the generation of stretching new requirements, fuelled by emerging technologies and successful demonstrators, eventually leads to competitive products. Military funding of targeted long-term research therefore ultimately drives the generation of world class, competitive exports, which in turn sustain the industrial supply base.

21. From a Departmental perspective, selective investment in targeted long-term research fuels the technology 'conveyor belt', which drives innovative requirements and shapes future equipment solutions. If the conveyor belt is decoupled from procurement processes, then not only does this threaten the viability and long-term survival of the UK Defence Industry, but it also puts the MOD in a position of declining technological influence over future equipments and concepts, and renders any prospect of retaining appropriate, adequate sovereignty of supply increasingly unrealistic.

Glossary

AAM	Air-to-Air Missiles
A&SCS	Avionics and Safety Critical Software
AeIGT	Aerospace Innovation and Growth Team
ACARE	Advisory Council for Aerospace Research in Europe
A-D	Analogue to Digital
AESA	Active Electronically Scanned Array
AFV	Armoured Fighting Vehicle
AI	Artificial Intelligence
ALARP	As Low As Reasonably Practicable
ALM	Air and Littoral Manoeuvre
AMSAR	Airborne Multi-mode Solid-state Active-array Radar
ARTS	Advanced Radar Targeting System
ASICs	Application Specific Integrated Circuits
ASTRID	Ammunition System Two Revision and Interactive Development
ASW	Anti-Submarine Warfare
ATR	Automatic Target Recognition
ATSG	Aerospace Technology Steering Group
BABT	Behind Armour Blunt Trauma
BCS	British Computer Society
BDA	Battle Damage Assessment
BDI	Battle Damage Information
BIL	Burst Illumination Laser Imaging
BoI	Balance of Investment
BVR	Beyond Visual Range
BW	Biological Warfare
C2	Command and Control
C4ISTAR	Command, Control, Communication, Computers, Intelligence, Surveillance Target Acquisition and Reconnaissance
C-DIRCM	Compact Directed Infra Red Counter Measures
CAD	Computer Aided Design
CB	Chemical Biological
CBM	Command and Battlespace Management
CBRN	Chemical Biological Radioactive Nuclear
CCII	Command, Control and Information Infrastructure
CCIRM	Collection Coordination and Information Requirements Management
CCM	Counter-Countermeasures
CESG	Communications and Electronic Security Group
CFD	Computational Fluid Dynamics
CGDA	Common Geographic Database Architecture
CIS	Communications and Information Systems
CM(IS)	Capability Manager (Information Superiority)
CMT	Cadmium Mercury Teluride
Conops	Concept of Operations
COTS	Commercial Off The Shelf
CR	Cognitive Radio
CSA	Chief Scientific Adviser
CSEP	Certified Systems Engineering Professional
CSP	Capability Sustainment Programme
CT	Counter Terrorism
CTSTC	Counter Terrorism Science and Technology Centre
CW	Complex Weapons
CWG	Capability Working Group
CWID	Coalition Warrior Interoperability Demonstration
CWIT	Complex Weapons Implementation Team
D&D	Denial and Deception
DA	design authority
DARA	Defence Aviation Repair Agency
DARPA	Defense Advanced Research Projects Agency
DAS	Defensive Aid System
DCDC	Development, Concepts and Doctrine Centre
DCL	Detection, Classification, Localisation
DCPD	Direct-Collect-Process-Disseminate
DCTA	Defense Clothing and Textiles Agency
DEC	Director Equipment Capability
DEFCON	Defence Conditions
DEFRA	Department for Environment, Food and Rural Affairs
DEW	Directed Energy Weapon
DIF	Data Information Fusion
DIF DTC	Data & Information Fusion DTC
DIRCM	Directed Infra Red Counter Measures
DIS	Defence Industrial Strategy, Defence White Paper, Dec 2005
DLO	Defence Logistics Organisation
DLOD	Defence Line of Development
DNAE	Day/Night/All Environment
DoD	Department of Defense
DPA	Defence Procurement Agency
DRFM	Digital Radio Frequency Memories
DSAC	Defence Scientific Advisory Council
DSP	Digital Signal Processing
Dstl	Defence Science and Technology Laboratory
DTC	Defence Technology Centre
DTI	Department of Trade and Industry
DTS	Defence Technology Strategy
DU	Depleted Uranium
DVI	Direct Voice Interaction
EA	Electronic Attack
ED	Electronic Defence
EDA	European Defence Agency
eHALE	electric High Altitude Long Endurance
EI	Environmental Information
ELINT	Electronic Intelligence
ELS	Expeditionary Logistics and Support
EM	Electromagnetic
EMC	Electro-Magnetic Compatibility
EMCDB	Elastomer Cast Double Base Propellants
EMRS	Electro Magnetic Remote Sensing
EO	Electro-optic
EO	Earth Observation
EOB	Electronic Order of Battle

EOCM	Electro-optic Countermeasures
EOD	Explosive Ordnance Disposal
EOPM	Electro-Optic Protective Measures
EP	Equipment Plan
EPSRC	Engineering and Physical Sciences Research Council
ERA	Explosive Reactive Armours
ES	Electronic Surveillance
ES	Electronic Systems
ES	Electronic Support
ESM	Electronic Support Measures
ESAU	Electronic Safety and Arming Units
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUT	Emerging and Underpinning Technologies
EW	Electronic Warfare
FCO	Foreign and Commonwealth Office
FCS	Fire Control System
FDOA	Frequency Difference of Arrival
FIST	Future Infantry Soldier Technology
FMCMC	Future Mine Counter Measure Capability
FPA	Framework Partnering Agreement
FPE	Force Protection Engineering
FPGA	Field Programmable Gate Array
FRES	Future Rapid Effect System
FSA	Food Standards Agency
FSP	Future Submarine Programme
FW	Firmware
FW	Fixed Wing
FWD	Flightworthy Demonstrator
GaAs	Galium Arsenide
GaN	Galium Nitride
GM	Ground Manoeuvre
GMLRS	Guided Multi Launch Rocket System
GMTI	Ground Moving Target Indication
GPS	Global Positioning System
GSR	General Service Respirator
HAIPE	High Assurance Internet Protocol Encryption
HAIPIS	High Assurance Internet Protocol Interoperability Specification
HALE	High Altitude Long Endurance
HCI	Human Computer Interaction
HF	High Frequency
HFI	Human Factors Integration
HFNAC	Human Factors National Advisory Committee
HI&SCS	High integrity and safety critical software
HIFAWS	High Field Asymmetric Wave Spectroscopy
HMD	Helmet Mounted Displays
HMI	Human-Machine Interface
HO	Home Office
HOT	High Operating Temperature
HOTAS	Hands on Throttle and Stick
HQ	Headquarters
HS	Human Sciences
HSW	High Speed Weapon
HUD	Head-up Display
HumInt	Human Intelligence
HUMS	Health Usage and Monitoring System
HW	Hardware
HWIL	Hardware in the Loop
IAWG	Industrial Avionics Working Group
ICA	Independent Component Analysis
ICS	Intelligent Customer Status
ICT	Information and Communications Technology
ID	Identification
IDM	Improved Data Modem
IED	Improvised Explosive Device
IEE	Institution of Electrical Engineers
IER	Information Exchange Requirements
ILS	Integrated Logistics Support
IM	Insensitive Munitions
IMSSA	Integrated Modelling and Simulation Support for Acquisition
IMU	Inertial Measurement Unit
InAs	Indium Arsenide
INCOSE	International Council of Systems Engineering
InSb	Indium Antimonide
IO	Information Operations
IO	Input Output
IP	Intellectual Property
IP	Internet Protocol
IPR	Intellectual Property Rights
IPT	Integrated Project Team
IR	Infra-red
IRC	International Research Collaboration
IRC	Interdisciplinary Research Centre
IRST	Infra Red Search and Target
ISD	In-Service Date
ISEE	Integrated Sensor Evaluation Environment
ISMS	Integrated Sensor Management System
ISP	Intelligent Signal Processing
ISR	Intelligence, Surveillance, Reconnaissance
ISTAR	Intelligence, Surveillance Target Acquisition and Reconnaissance
IT	Information Technology
ITP	International Technology Partnership
JCA	Joint Combat Aircraft
JIMSG	Joint Insensitive Munitions Strategy Group
JSF	Joint Strike Fighter
KE	Kinetic Energy
KUR	Key User Requirement
LAASS	Low Altitude Airborne Sensor System
LCAD	Lightweight Chemical Agent Detector
LED	Light Emitting Diode
LEFIS	Link Encryptor Family Interoperability Specification
LFE	Link Encryption Facility
LIDAR	Light Detection and Ranging
LO	Low Observable
LOVA	Low Vulnerability Ammunition
LPD	Landing Platform Dock
LPI	Low Propability of Intercept
LTPA	Long Term Partnering Agreement
M&S	Modelling and Simulation
MASS	Munition Acquisition Supply Solution
MAV	Micro Air Vehicles
MAW	Missile Approach Warners
MCM	Mine Counter Measures
MEDL	Munition Environmental Data Loggers
MEMS	Micro-Electro-Mechanical Systems
MFA	Multi-function Apertures
MIDAS	Military Integrated Defensive Aid System

MIMO	Multiple-Input Multiple-Output
MIS	Maritime Industrial Strategy
MLU	Mid-Life Update
MMS	Mission Management System
MMW	Millimetric Wave
MOD	Ministry of Defence
MODAF	Ministry of Defence Architecture Framework
MOTS	Military Off the Shelf
MSR	Major Supply Route
MTBF	Mean Time Between Failure
MTS	Maritime Technology Strategy
MW	Mid-ware
NAC	National Advisory Committee
NATO	North Atlantic Treaty Organisation
NAVWAR	Navigation Warfare Programme
NBC	Nuclear Biological Chemical
NBC BISA	Nuclear, Biological and Chemical Battlefield Information System Application
NDE	Non-Destructive Evaluation
NDEC	National Defence Energetics Community
NDIC	National Defence Industries Council
NEC	Network Enabled Capability
NELS	Networked Emitter Location System
NGOSS	New Generation Operations Support System
NITEworks	Network Integration Test and Experimentation works
NLW	Non-Lethal Warfare
NQR	Nuclear Quadrupole Resonance
NSRP	Nuclear Steam Raising Plant
NVG	Night Vision Goggles
OA	Open Architectures
OA	Operational Analysis
ODPM	Office of the Deputy Prime Minister
OEM	Original Equipment Manufacturer
OEU	Operational Evaluation Unit
OGD	Other Government Department
OS	Operating Systems
OSI	Office of Science and Innovation
OTS	Off The Shelf
PBX	Polymer Bond Explosives
PCR	Passive Covert Radar
PKI	Public Key Infrastructure
PSDB	Police Scientific Development Branch
PV	Private Venture
R&D	Research and Development
R&T	Research and Technology
RAEng	Royal Academy of Engineering
RAF	Royal Air Force
RAM	Radar Absorbent Materials
RAO	Research Acquisition Organisation
RCS	Radar Cross Section
RCV	Remote Controlled Vehicle
RF	Radio frequency
RFI	Request for Information
RFID	Radio Frequency Identification
RN	Royal Navy
RoE	Rules of Engagement
RoW	Rest of the World
RPG	Rocket Propelled Grenade
RSS	Really Simple Syndication
RTO	Research and Technology Organisations
RWR	Radar Warning Receiver
S2C2	Sustainable Surface Combatant Capability
S&T	Science and Technology
SA	Situational Awareness
SAA	Small Arms Ammunition
SAC	Submarine Atmosphere Control
SAL	Semi-Active Laser
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SAR	Search and Rescue
SAU	Safety and Arming Unit
SCIP	Secure Communication and Interoperability Protocol
SCS	Safety Critical Software
SDR	Strategic Defence Review
SE	Systems Engineering
SE	Synthetic Environment
SEAD	Suppression of Enemy Air Defences
SEAS	Systems Engineering for Autonomous Systems
SF	Special Forces
SG	Support Group
ShyFE	Sustained Hypersonic Flight Experiment
SIAP	Single Integrated Air Picture
SiGe	Silicon Germanium
SIL	Systems Integration Laboratory
SIT	Science Innovation Technology
SME	Small and Medium-sized Enterprise
SP	Special Projects
SSEI	Software System Engineering Initiative
STP	Short Term Plan
SSK	Conventional Submarine
SVD	Singular Value Decomposition
SW	Software
SWAP	Size, Weight and Power
SWOT	Strengths, Weaknesses, Opportunities and Threats
T&E	Tested and Evaluated / Test and Evaluation
TDL	Tactical Data Link
TDOA	Time Difference of Arrival
TDP	Technology Demonstrator Programme
TEEMAC	Terminal Effects and Energetic Materials Advisory Committee
TI	Thermal Imaging
TICM	Thermal Imager Common Module
TLB	Top-Level Budget
TLCM	Through-Life Capability Management
TLM	Through-Life Management
ToE	Tower of Excellence
TRDs	Towed radar decoys
TR Module	Transmit - Receive Module
TRaME	Tactical Radiation Monitoring Equipment
TRL	Technology Readiness Level
TST	Time Sensitive Targeting
TTP	Tactics, Techniques and Procedures
UAS	Unmanned Air System
UAV	Unmanned Air Vehicle
UCAS	Unmanned Combat Air System
UCAV	Unmanned Combat Air Vehicle
UHF	Ultra High Frequency
UMV	Unmanned Maritime Vehicle
UOR	Urgent Operational Requirement
UPC	Unit Purchase Cost
URD	User Requirement Document

UUV	Unmanned Underwater Vehicle
UV	Ultra Violet
UW	Underwater
UXV	Unmanned Vehicles (Air, Above Water, Under Water or Land)
VFM	Value for Money
VHF	Very High Frequency
WLC	Whole Life Cost
WMD	Weapons of Mass Destruction

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contact details

science | innovation | technology

Ministry of Defence
Main Building
Whitehall, London
SW1A 2HB

0207 218 6626

www.science.mod.uk
Email:science@mod.uk